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Habitat dynamic and elevational gradient influences the phenotypic attributes of Aconitum chasmanthum Stapf ex Holmes

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Table 1 to 3 are available in the Supplementary Files section.

Habitat dynamic and elevational gradient influences the phenotypic attributes of *Aconitum chasmanthum* Stapf ex Holmes

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Abstract

Aconitum chasmanthum Stapf ex Holmes is a critically endangered valuable herb with high medicinal potential. Phenotypic attributes of a particular plant species fluctuate across various climatic conditions and elevational gradients to withstand the demanding stressful settings. This study was intended to shed light on the effects of altitude and environmental factors on the morphological characteristics and phenology of *A. chasmanthum.* The quantitative morphological characters were studied in eleven natural populations across Kashmir Himalaya. The population of ACIII and ACIV have a short growing season and completed their phenological episodes within 135 days followed by ACVI. *A. chasmanthum* growing in open grassy slopes at an altitude of 3234m asl showed better growth and development in all morphological traits whereas plants growing at higher altitude ACIII (3712m asl) exhibited stunted growth and development in all the quantitative morphological traits viz (height; petiole, leaf, pedicel and rhizome dimensions). Linear regression analysis revealed a gradual reduction in morphological attributes with an increase in elevation. Pearson correlation value revealed a positive association between plant height and all other morphological characteristics. Principal component analysis (PCA), has shown that ACI, ACII and ACV had habitats, ecological conditions, and altitudes that were relatively more suited for the luxuriant growth and development of the endemic plant species *A. chasmanthum*. From the observations, it can be inferred that open moist grassy stable slopes are better suited for its growth than open moist rocky slopes and banks of small alpine rivulets. This study offers a thorough description of phenotypic variation with environmental circumstances and suggests a habitat that is suited for the sustained cultivation of this significant medicinal plant species in the Kashmir Himalaya.

Keywords Distribution · Conservation · Habitat variability · Morphology ·Phenology · Threats

Introduction

Alpine habitats are characterized by abrupt environmental changes over small distances [1]. The alpine landscape is naturally fragmented and exhibits significant spatial variability as a result of the compression of climatic living zones over condensed geographical distances. The high biodiversity of alpine plants is a result of the variety of microhabitats, but it also causes geographic isolation between populations and constrained gene flow [2, 3]. In addition, plants at higher elevations must contend with reduced air pressure, lower temperatures, a shorter vegetative

phase, a smaller window for reproduction, as well as greater snowfall and weather-related severe occurrences [4,5]. Plants can either genetically adapt to local circumstances to live in such diverse and challenging environments, or they can respond to environmental variability through phenotypic plasticity [6, 7].

Local adaptation improves a population's success in its specific habitat [8], but phenotypic variability allows a single genotype to exhibit several phenotypes in response to environmental factors [9-11]. Since plants cannot move and must adapt to changing environmental conditions, phenotypic variability permits organisms to respond quickly to a changing environment [10, 6] because it allows quick adaptation to a temporally highly changeable environment. Phenotypic adaptability is also expected to occur more often at higher elevations, guaranteeing the survival of alpine plants [2, 12]. Though not always beneficial, variability can sometimes be nonadaptive and have a neutral or worse impact on fitness [13]. Genetically fixed features may be preferred in some situations, which are often temporally stable [14, 15], due to the costs and restrictions associated with the development and maintenance of variability [16]. To forecast how plants will adapt to future climate change, it is necessary to understand whether and how much a species can adapt phenotypically to a changing environment. If phenotypic modifications are restricted, plants would either need to quickly adapt to the new conditions genetically or move to follow the conditions they are now accustomed to [17]. If a climatic change occurs quickly, the fitness of locally adapted plants may fall fast, increasing the likelihood of local extinction, particularly for isolated, inbred, and apomictic species [18, 19, 17].

One of the most effective "natural experiments" for examining how the biota responds to geophysical factors like low temperatures are to use of altitudinal gradients [20]. Plant physiologists, ecologists, and paleobotanists are all very interested in the connection between altitude and plant form. High-altitude species typically differ from closely similar species at lower elevations in terms of morphology and physiology. According to [21], altitude also has a significant impact on the morphology and physiology of leaves within a species.

The phenology of any plant species is strongly dependent on climatic conditions at higher elevations, particularly in mountain environments [22, 23]. To ensure the reproductive success of plant species, several environmental elements, including elevation, temperature [24, 25], soil moisture, photoperiod, and snowmelt, influence floral phenology [1, 26]. Complex biotic elements (flora and fauna) and abiotic elements (soil, temperature, precipitation, moisture, etc.) are provided by the elevational gradient, which experiences significant variations with elevation [20]. As a result, the physical complexity in the mountains promotes speciation and increases isolation, leading to a rise in species richness, beta diversity, and turnover with elevation [20, 27, 28].

Aconitum chasmanthum Stapf ex Holmes (Ranunculaceae), commonly known as Gaping Monkshood, Vatsanabha, locally known as Mohand, Mohand posh, Mohand gurd is a biennial herb, having an erect stem, reaching 60 to 90 cm in height [29], numerous leaves and hermaphrodite flowers aggregated in racemes. The IUCN has classified it as severely endangered [30], with an extremely limited range. Native to Pakistan and India, it can grow in the western Himalayas. It is most common in the subalpine and alpine zones, from Chitral and Hazara between 2300 and 4300 m [31] to Kashmir and Himachal Pradesh between 2100 and 3600 m asl [32, 29]. It prefers light (sandy) soils with mildly alkaline (basic soils), but it can also grow in medium (loamy) and heavy (clay) soils. It prefers moist but well-drained soils.

Aconitum chasmanthum is a critically endangered medicinal plant with unparalleled therapeutic properties and is widely used in numerous Southeast Asian nations [33]. *A. chasmanthum* is associated with various biological activities as it has a large number of phytocompounds. Locals use its rhizome to treat diseases such as fever, rheumatism, cough, asthma, and snake bites [34, 35], and after being combined with butter oil, its rhizome powder is used as an ointment to treat boils and abscesses [36]. It serves as an appetizer to soothe pain and inflammation [37], as well as for cardiovascular disease, anodyne, anti-diabetic, tonsillitis, astringent, diarrhoea, neurasthenic, cold and cough purposes [38-40]. Its rhizomes have been documented for various microbial activities including antifungal, insecticidal, antibacterial [31] and antioxidant effects [41].

Materials and Methods

To explore phenotypic plasticity and phenology under various environmental and altitudinal conditions, a dynamic approach was adopted in the current study. Data on several morphometric traits were collected to uncover features of phenotypic variability. The survey was carried out from May 2019 to October 2021.

Exploration, collection and documentation

Different regions of the Kashmir Himalaya (India) were extensively surveyed and explored to select different study sites in the region. Eleven sites: Bangus valley-I (2913m asl), Bangus valley-II (3214m asl), Pahalgam- I (3712m asl), Pahalgam-II (3642m asl), Gulmarg (3234m asl), Farhad's Canal Ganderbal (3673m asl), Maloodh Ganderbal-I (3457m asl), Maloodh Ganderbal-II (3256m asl), Gurez (3728m asl), Razdhan Pass-I (3270m asl), Razdhan Pass-II (3423m asl), were chosen to explore the variation in phenotypic traits based on their accessibility, habitat characteristics, and prevailing environmental conditions along an altitudinal gradient. The geographic location of the chosen sites is shown on the table 1 and also on map (Fig. 1). Given adequate consideration for the critically endangered status, vigorous adult blooming plants of *Aconitum chasmanthum* Stapf ex Holmes were very carefully picked from several study sites. The specimen was identified and authenticated by Dr. Anzar Ahmad Khuroo at the Centre for Biodiversity and Taxonomy (CBT), Department of Botany, University of Kashmir, Hazratbal, Srinagar. A voucher specimen were submitted under accession number (2939-KASH) has been deposited at the Kashmir University Herbarium (KASH). From each study site, 10 to 15 specimens of the species were randomly selected and tagged. Between May 2019 to October 2022, the tagged individuals underwent routine monitoring. The related species of the chosen location, vegetation type, habitat, geo coordinates, and heights were noted (Table 1).

Phenology

Initiation, duration and completion of various phenophases viz sprouting of underground rhizome, floral bud formation, anthesis, peak flowering, seed maturation and complete senescence of aerial parts were undertaken in eleven natural populations. 15 individuals were randomly selected from each population and marked with aluminum tags and monitored during the growing seasons of three consecutive years (2019, 2020 and 2021).

Species Morphology and Phenotypic Variability

At regular intervals of 10-15 days, the population's randomly chosen members of the population were continuously monitored. Variations in morphological characteristics, such as plant height, rhizome, petiole, leaf, and pedicel dimensions were noted. To identify the places where this species grows best, we performed linear regression analysis to ascertain the link between several morphological features along the altitudinal gradient. To assess the morphological features in connection with habitat dynamics, principal component analysis (PCA) was used.

Statistical analysis

Microsoft Excel was used to calculate the average and standard error for LSD and Tukey's test (one-way ANOVA) to compare the significant level (MS-office-16). To identify the best habitat for improved growth and development, the link between distinct morphological traits across various environmental conditions and altitudes was examined using linear regression and Pearson's correlation coefficient analysis. To display the lowest, median, and maximum values of each variable, box plots were created. The coefficient of variation (CV) for each trait was calculated as a complementary index to evaluate intraspecific variation using the formula: CV = standard deviation/mean ×100. The population's phenotypic plasticity index (PPI) was determined using the formula: PPI = maximum mean - lowest mean / maximum mean [42, 43]. To evaluate the phenotypic characteristics with various habitat circumstances, principal component analysis (PCA) was used. The PCA was examined using Origin-Pro 2019b 64 software, and the correlation was discovered using R (version 4.1.2; 64-bit) software. Data was gathered for 10-15 plants from each community to evaluate the variation in phenotypic characteristics. A Canon DSLR (1300D), and a Realme X3 superzoom smartphone camera was used to shoot the pictures.

Results

Distribution

Aconitum chasmanthum Stapf ex Holmes is locally known as Mori, Mohand, Mohand posh, Mohandgurd. In the Kashmir Himalaya, *A. chasmanthum* is distributed in the alpine and sub-alpine regions of Ganderbal (Farhad Kul, Maloodh, Sonmarg, Vishansar), Baramulla (Apharwat Gulmarg, Kangdoori Gulmarg, Khilanmarg Gulmarg, Uri), Bandipora (Razdhan Pass, Gurez, Chorwan Gurez, Khupri Gurez, Dahinala Gurez), Anantnag (Rayil lake, Posh phatri, Mahaganesh top), Kupwara (Bangus Valley), Shopian (Hirpora Wild Life Sanctuary), Srinagar (Dachigam National park), Budgam (Hapatkhod Yusmarg) at altitudes ranging from 2900-4000 m altitudes. The northeastern part of the Kashmir Himalaya contains the maximum population of *A. chasmanthum,* and the selected areas of the distribution pattern are shown in the map (Fig.1). In the Kashmir Himalaya, it is mostly distributed along the banks of small alpine rivulets, moist damp slopes, open grassy and moist grassy slopes, and open meadowlands and open moist meadowlands (Table 1). It grows luxuriantly in open moist; but well-drained slopes and is strongly associated with species like *Bergenia ciliata*, *Iris* spp., *Fragaria* spp., *Dryopteris* spp., *Swertia* spp., *Geranium* spp., *Podophyllum hexandrum*, *Rumex* spp., *Epilobium* spp., *Jurinea* spp., *Fragaria* spp., *Juniperus* spp., *Meconopsis aculeata*, *Primula* spp., *Centella* spp., *Indigofera* spp., *Centurea* spp., *Ranunculus* spp., *Geranium* spp., *Polygonum* spp., *Saussurea costus* and *Thalictrum* spp. etc.

Threats faced

Aconitum chasmanthum faces the onslaught of extinction from the region due to various biotic and abiotic factors and is facing the threat of extinction in its natural habitat (Fig.2). According to the IUCN Red List of threatened species, *A. chasmanthum* has been accessed as critically endangered (IUCN 2015). The main threats it faces in its natural habitat include a long period of dormancy (>5 months) due to its hard seed coat and the reduced light access of being buried under the litter of other species (photoblastic nature), as well as a long period of winter [44]. In snowfall, the seeds of this plant experience a long period of dormancy. The seeds are at risk of being washed away by severe rains and snow avalanches from their native environment, thus exposing them to adverse environmental conditions. Their survival rates and abundance are significantly affected by competition with other species after the germination of disseminated seeds [45]. While the plant, the entire species is rooted, which hinders the regrowth of the species by preventing flowering and seed development. *A. chasmanthum* mostly thrives in open, damp, rocky slopes, making it susceptible to landslides, avalanches, and other natural disasters that might wipe out its native populations. Grazing and tramping of seedlings by cattle and overharvesting lead to the loss of their natural populations [45]. The construction of tourism huts and high-altitude roads has led to habit fragmentation (Fig. 2a–c). Furthermore, the species has a highly specialised ecological niche that may potentially restrict its range of expansion and dispersion [45]. Beetles and aphids (Fig. 2 d,e,f **)** are two additional possible threats to the species since they feed on floral buds and consume the reproductive section of the plant, further lowering the species reproductive capacity [35] and the same threats has been reported for *A. violaceum* [46] from Ladakh Himalaya.

Phenological events

The phenophase of *A. chasmanthum* starts from the germination of an underground rhizome. The specific phenophases vary within different populations. The population ACIII and ACIV exhibited a short growing season and complete their life cycle within 135 d (Germination of the underground rhizome started on the 2nd week (wk) June and showed complete senescence on the 4th wk of September) followed by the population ACVI, whereas the ACI and ACII populations possessed a long growing season of 178 d. The underground rhizome started growing in the 4th wk of April and completed the senescence of aerial parts in the 3rd or 4th wk of October. The detailed phenophases were summed up in Fig. 3. The production of floral buds, which partially overlaps with the sprouting process. Anthesis begins around the first week of July and lasts till the first week of September.

Species morphology and phenotypic variability

The morphological characteristics of *A. chasmanthum* are summarised in (Table 2, Fig. 4). At various elevations and climates, the phenotypic traits of *A. chasmanthum* exhibited substantial diversity. These phenotypic variations were observed at 11 particular locations **(**Table 1**)**. The following morphological traits were evaluated for phenotypic variability: average plant height, average rhizome length, average rhizome width, average petiole length, average leaf length, average leaf width, average pedicel length, average flower length, average flower width, average follicle length, average seed length, and average seed width (Table 3). Populations from the chosen sites had noticeable

variances in phenotypic features, altitude, and environmental factors. The average plant height varies from 26.62 ± 1.23 cm to 85.8 ± 2.40 cm, the fresh rhizome length is 2.57 ± 0.25 cm to 5.75 ± 0.50 cm, the fresh rhizome girth is 2.62 ± 0.15 cm to 5.08 ± 0.29 cm, the basal petiole length 4.58 ± 0.44 cm to 10.75 ± 1.15 cm, the basal leaf length 3.21 ± 0.31 cm to 8.02 ± 0.62 cm and the basal leaf width 4.79 ± 0.43 cm to 10.05 ± 0.5 cm (Table 3).

Additionally, the apical leaf length ranges from 1.275 ± 0.20 cm to 2.08 ± 0.2 cm, the width of the apical leaf is 0.81 ± 0.15 cm, to 1.62 ± 0.32 cm and the leaf number per plant is 9.25 ± 0.77 cm to 22.4 ± 1.47 cm (Table 3). The average floral number per plant varied from 14.0 ± 0.46 cm to 33.8 ± 2.22 cm, while the average pedicel length varied from 3.31 ± 0.44 cm to 4.12 ± 0.42 cm (Table 3). Most quantitative morphological features exhibited an inverse relationship with altitude (i.e., they displayed a steady decline as altitude increased). The examined morphological traits differ greatly among the chosen groups. Along with the altitude, the various populations displayed a great deal of morphological variation. The ACV population has the highest values for almost all physical features when compared to the other populations. The Bangus valley (ACI and ACII) populations showed morphological characteristics almost similar to the Gulmarg population, followed by the Razdhan populations (ACX and ACXI), while the Rayil Phalgham populations (ACIII and ACIV) exhibited the lowest values for morphological features.

Morphological attributes showed high variation (Fig. 5 and Fig. 6). Coefficient of variation (CV) was 36.18% for plant height, 27.12% for fresh rhizome length, 21.68% for fresh rhizome girth, 32.8% for basal petiole length, 34.79% for basal leaf length, 29.58% for basal leaf width, 17.81% for apical leaf length, 26.51% for apical leaf width, 6.9% for pedicel length, 29.26% for flower number and 35.55% for leaf number. All morphological characters showed significant variation among subpopulations. Phenotypic plasticity index for 11 morphological characters is shown in Fig. 7. High phenotypic plasticity was observed for plant height (0.68), fresh rhizome length (0.55), fresh rhizome girth (0.48), basal petiole length (0.57), basal leaf length (0.59), basal leaf width (0.52), apical leaf length (0.39), apical leaf width (0.5), pedicel length (0.2), flower number (0.58) and leaf number (0.59).

Plant height and other quantitative features exhibited a positive relationship (i.e., individual plants with large height have larger growth forms for other phenotypic traits such as rhizome, leaf dimension, leaf number and flower number etc.). There was a negative correlation between plant height and elevation (r^2 = 0.75415), and a positive correlation between plant height and fresh rhizome length (r^2 = 92628), plant height and basal petiole length (r^2 = 0.84399), plant height and basal leaf length (r^2 = 0.90731), plant height and flower number (r^2 = 0.96386), plant height and leaf number (r^2 = 0.87582) as shown in (Fig. 5). Almost all quantitative phenotypic variables (such as rhizome diameter, leaf dimension, leaf number, inflorescence length, flower number, etc.) were positively correlated according to Pearson's correlation coefficient (Fig. 8). According to Principal Component Analysis (PCA), physical characteristics gradually get smaller as the altitude increases and vice versa (Fig. 8). The first three PCA's explained 98.4% of the total variance (92.7, 3.8 and 1.9% respectively). The population growing at Gulmarg, Bangus Valley and Razdhan Pass grew most luxuriantly and showed the highest phenotypic traits, whereas the population growing at high elevation (Rayil Phalgham) showed a decrease in size of all phenotypic traits compared to other populations, separating them from the rest of the other populations of the study site.

Discussion

Plants growing in vast elevational gradients in mountains endure significantly diverse abiotic and biotic environments that alter dramatically over relatively short vertical distances. Because both the biotic and abiotic elements of elevation in mountains are essential for plant growth, they cannot be easily distinguished from each other. Because of this, studies on the phenotypic variation of plant species in mountains have focused on the elevational gradient [2, 47, 48, 49, 50, 51, 52, 53]. Plants can adapt locally and respond to elevational changes depending on their morphological and physiological flexibility [54]. Species spread over broad elevational ranges exhibit intraspecific morphological variations along elevational gradients. Shorter stems, fever blossoms, and bigger flowers are all characteristics of plants that grow at higher elevations than those that do not [55, 56, 57, 58]. Along with an increase in elevation, plants also have better flower lifespan plasticity [59], as well as increased clonality [47]. Understanding the function of natural selection in plant adaptation to alpine settings and plant phenotypic responses to such conditions requires knowledge of differences in morphological features and plant performance in wild populations over elevational gradients [60, 61].

The extensive geographic spread and morphological variability of the *Aconitum* Genus make it significant for systemic research. Hadi et al have noted a high degree of phenotypic variability in the physical characteristics of *Aconitum violaceum* [62]. In the current study, *Aconitum chasmanthum* of the Kashmir Himalaya was found to have a high degree of morphological diversity in terms of the length of the fresh rhizome, the girth of the fresh rhizome, the length of the basal petiole, the length of the basal leaf, the width of the basal leaf, the length of the apical leaf, the width of the apical leaf, the length of the pedicel, the number of leaves per plant and flower number per plant. In terms of morphological characteristics, the impact of the altitudinal gradient was observed. High phenotypic diversity was observed in *A. chasmanthum* from the Kashmir Himalayan area, which was collected from an altitudinal range of 2913-3728m asl. Plants thriving at elevations ranging from 2900 to 3300 m asl (Gulmarg and Bangus Valley populations) were substantially more robust and diversified in all morphological traits. There was significant variation in phenotypic characteristics, and there was a general tendency toward a linear decline in plant features with elevation. As the altitude increases, there is a significant variation in the height of the plants. This is consistent with the observations made by [1, 63, 64, 62, 65] who also noted a reduction in plant size as an adaptation to the rising altitude. Increasing altitude causes plants to grow more slowly, helping them use resources more effectively in harsh climates [66]. This may be advantageous for the species since the stem shortening helps plants escape the negative impacts of strong winds [67], and the ability of plants to supercool at high altitudes is increased by smaller cells and intercellular gaps [68]. The physical traits of *A. chasmanthum* populations growing at various elevations in the Kashmir valley exhibited both a direct and a negative association with the altitude; significant phenotypic variation was also discovered within and between individuals of these populations.

The CV is a common and basic phenotypic variation metric used in many investigations. In an altitudinal gradient of 815m, we found a high CV for plant height (36.18%), basal petiole length (32.8%), basal leaf length (34.4%), basal leaf width (29.58), flower number (29.26), and leaf number (35.66). With comparison to[69], who observed 17.37%, 25.58%, 18.02%, and 17.19% of CV in regard to leaf length, leaf width, fruit length, and fruit width in wild

populations of *Vaccninium meridionale* over an altitudinal gradient of 2357-3168 m asl, with an altitudinal difference of 811m. In another study on *M. alba* conducted in the trans-Himalayan region (Ladakh), [70] found high CVs for leaf length (26.6%), leaf breadth (26.2%), petiole length (32.2%), and leaf area (50.3%) from an altitudinal range of 2815-3177m asl in a very small altitudinal gradient of 362 m. Phenotypic plasticity among populations was also analysed using phenotypic plasticity index (PPI). PPI is a popular plasticity measure that is both simple and reliable [43]. All morphological characteristics, particularly the plant height, basal leaf length, flower number and leaf number, showed high plasticity. In reaction to environmental change, plants either passively limit their growth in low resource environments or actively boost resource acquisition in each habitat with sufficient resources [71, 72]. Consequently, when altitude varies, the climate also alters, which causes variations in the way that resources are acquired. These differences in pattern are then seen in phenotypic.

Phenology, the study of recurring seasonal natural phenomena, can assist scientists in comprehending changes in Alpine plants brought on by the effects of global warming [73] and can have a significant impact on a species reproductive success [74]. Unquestionably, one of the best methods to see and understand how a specific plant species interacts with and responds to changing environmental conditions is through the study of phenology. Because it affects pollinator attraction and reproductive synchrony with possible mates [75], flowering phenology is particularly significant [76]. In particular, flowering phenology is significant as it affects pollinator attraction [76] and reproductive synchrony with possible pollinators [75]. Altitude mostly controls the phytophenological phases by causing temperatures to drop by around 0.6 °C per 100m [77]. By regulating synchronization to, and subsequent sensitivity to floral herbivores and seed predators, flowering timing may also have a significant impact on reproductive success [78]. Therefore, it is clear that phenological events are very beneficial in establishing conservation strategies for species that are threatened as well as creating procedures for commercial cultivation [79, 80]. Flowering is the longest phenophase in the species out of all phenophases. Due to the prolonged blooming time, there is a greater likelihood that an individual will have a large number of partners available to act as both pollen givers and receivers, maximising their reproductive potential.

Conclusion

The current study found that *A. chasmanthum* populations in the Kashmir Himalaya differ significantly in terms of physical characteristics. Along an altitudinal gradient, *A. chasmanthum* generally showed substantial phenotypic variation. The findings indicated that even a slight rise in altitude created significant challenges for plants trying to live in the Kashmir Himalayan environment. According to this study, phenotypic plasticity helps sustain observed phenotypic variance to some extent. To forecast how plants will react to future environmental changes, including those brought on by global warming, it is essential to comprehend the role played by phenotypic plasticity. *A. chasmanthum* in the Kashmir Himalaya's phenotypic plasticity might be used as a model system to explore how plants will adapt to changing environmental conditions in the future. This work also has evolutionary importance as it offers a fundamental overview of the phenotypic variation of *A. chasmanthum* in the Kashmir Himalayan area for future research.

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Author contributions SR: investigation, writing - review, editing and analysis. AH: investigation, writing - review, editing and analysis. AH, SR: draft preparation, review. ZAK: validation, methodology, software, data curation. MM: draft preparation and review. NAW: investigation, validation, data curation. SA: Assisted in field survey, characterization

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Data Availability:

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Not applicable, as this is plant-based study.

Consent for publication

Not applicable

Plant reproducibility:

Plant material of *Aconitum chasmanthum* Stapf ex Holmes Clarke were selected from 11 locations in the Kashmir Himalaya, India: Bangus valley-I (2913m asl), Bangus valley-II (3214m asl), Pahalgam- I (3712m asl), Pahalgam-II (3642m asl), Gulmarg (3234m asl), Farhad's Canal Ganderbal (3673m asl), Maloodh Ganderbal-I (3457m asl), Maloodh Ganderbal-II (3256m asl), Gurez (3728m asl), Razdhan Pass-I (3270m asl), Razdhan Pass-II (3423m asl. The specimen was identified and authenticated by Dr. Anzar Ahmad Khuroo at the Centre for Biodiversity and Taxonomy (CBT), Department of Botany, University of Kashmir, Hazratbal, Srinagar. A voucher specimen was submitted under accession number (2939-KASH) has been deposited at the Kashmir University Herbarium (KASH) for future reference.

The studied species (*Aconitum chasmanthum* Stapf ex Holmes Clarke) is indeed enlisted in both IUCN Red List of threatened Species and CITES Appendices. To minimize any impact on natural populations, phenotypic observations and measurements were conducted on living plants in their natural habitats without damaging or removing plant parts. Seed-related data were recorded only after natural seed dispersal. No destructive sampling of individuals was undertaken for the purposes of this study. All field investigations and experimental procedures were carried out in accordance with applicable institutional, national, and international guidelines and regulations governing biodiversity research and the conservation of threatened plant species. The research was observational in nature and focused on documenting phenotypic variations across altitudinal gradients. As no protected plant material was collected, transported, traded, or subjected to destructive experimental procedures, the study posed negligible risk to

the species or its habitat. Necessary permissions for field access and research activities were obtained from the relevant authorities prior to conducting the study.

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References

Korner C. Alpine Plant Life: Functional Plant Ecology of High Mountain Ecosystems. Springer, Berlin. 2003 https://doi.org/10.1007/978-3-642-18970-8

Stöcklin J, Kuss P, Pluess AR. Genetische Vielfalt, phänotypische Variabilität und lokale Adaptation in der Alpenlandschaft: Fallstudien mit vier alpinen Pflanzenarten. Botanica Helvetica. 2009;119:125-133. . https://doi.org/10.1007/s00035-009-0065-1

Frei ES, Scheepens JF, Stöcklin J. High genetic differentiation in populations of the rare alpine plant species Campanula thyrsoides on a small mountain. Alpine Botany. 2012 ;122(1):23-34. . https://doi.org/10.1007/s00035-012-0103-2

Billings WD, Mooney HA. The ecology of arctic and alpine plants. Biological reviews. 1968;43(4):481-529. https://doi.org/10.1111/j.1469-185X.1968.tb00968.x

Bliss LC. Arctic and alpine plant life cycles. Annual review of ecology and systematics. 1971; 1:405-438. https://www.jstor.org/stable/2096935

Sultan SE. Phenotypic plasticity for plant development, function and life history. Trends in plant science. 2000; 5(12):537-542. https://doi.org/10.1016/S1360-1385(00)01797-0

Becker U, Colling G, Dostal P, Jakobsson A, Matthies D. Local adaptation in the monocarpic perennial Carlina vulgaris at different spatial scales across Europe. Oecologia. 2006;150(3):506-518. https://doi.org/10.1007/s00442-006-0534-9.

Jain SK, Bradshaw AD. Evolutionary divergence among adjacent plant populations. I. The evidence and its theoretical analysis. Heredity 1966; 21(3):407-441. https://doi.org/10.1038/hdy.1966.42

Bradshaw AD. Evolutionary significance of phenotypic plasticity in plants. Advances in genetics. 1965;13:115-155. https://doi.org/10.1016/S0065-2660(08)60048-6

Schlichting CD. The evolution of phenotypic plasticity in plants. Annual review of ecology and systematics. 1986;17:667–693. https://www.jstor.org/stable/2097012

Pigliucci M. Phenotypic plasticity: beyond nature and nurture. JHU Press; 2001.

Pluess AR, Frei E, Kettle CJ, Hahn T, Ghazoul J. Plant growth and fitness of Scabiosa columbaria under climate warming conditions. Plant Ecology & Diversity. 2011; 4(4):379-389.https://doi.org/10.1080/17550874.2011.618848

Ghalambor CK, McKay JK, Carroll SP, Reznick DN. Adaptive versus non-adaptive phenotypic plasticity and the potential for contemporary adaptation in new environments. Functional ecology. 2007; 21(3):394-407. https://doi.org/10.1111/j.1365-2435.2007.01283.x

Van Kleunen M, Fischer M. Constraints on the evolution of adaptive phenotypic plasticity in plants. New phytologist. 2005;166(1):49-60. https://doi.org/10.1111/j.1469-8137.2004.01296.x

Auld JR, Agrawal AA, Relyea RA. Re-evaluating the costs and limits of adaptive phenotypic plasticity. Proceedings of the Royal Society B: Biological Sciences. 2010; 277(1681):503-511. https://doi.org/10.1098/rspb.2009.1355

Banta JA, Dole J, Cruzan MB, Pigliucci M. Evidence of local adaptation to coarse-grained environmental variation in Arabidopsis thaliana. Evolution. 2007; 61(10):2419-2432. https://doi.org/10.1111/j.1558-5646.2007.00189.x

Jump AS, Peñuelas J. Running to stand still: adaptation and the response of plants to rapid climate change. Ecology letters. 2005; 8(9):1010-1020. https://doi.org/10.1111/j.1461-0248.2005.00796.x

Etterson JR, Shaw RG. Constraint to adaptive evolution in response to global warming. science. 2001; 294(5540):151-154. https://doi.org/10.1126/science.1063656

Theurillat JP, Guisan A. Potential impact of climate change on vegetation in the European Alps: a review. Climatic change. 2001; 50(1):77-109. https://doi.org/10.1023/A:1010632015572

Körner C. The use of 'altitude'in ecological research. Trends in ecology & evolution. 2007; 22(11):569-574. https://doi.org/10.1016/j.tree.2007.09.006

Hovenden MJ, Vander Schoor JK. Nature vs nurture in the leaf morphology of Southern beech, Nothofagus cunninghamii (Nothofagaceae). New Phytologist. 2004; 161(2):585-594. https://doi.org/10.1046/j.1469-8137.2003.00931.x

Zhao Y, Liu X, Li G, Wang S, Zhao W, Ma J. Phenology of five shrub communities along an elevation gradient in the Qilian Mountains, China. Forests. 2018; 9(2):58. https://doi.org/10.3390/f9020058

Bucher SF, Römermann C. Flowering patterns change along elevational gradients and relate to life-history strategies in 29 herbaceous species. Alpine Botany. 2020;130(1):41-58. https://doi.org/10.1007/s00035-020-00231-w

Cornelius C, Leingärtner A, Hoiss B, Krauss J, Steffan-Dewenter I, Menzel A. Phenological response of grassland species to manipulative snowmelt and drought along an altitudinal gradient. Journal of experimental botany. 2013; 64(1):241-251. https://doi.org/10.1093/jxb/ers321.

Kopp CW, Neto-Bradley BM, Lipsen LP, Sandhar J, Smith S. Herbarium records indicate variation in bloom-time sensitivity to temperature across a geographically diverse region. International journal of biometeorology. 2020; 64(5):873-880. https://doi.org/10.1007/s00484-020-01877-1.

Hartmann DL, Tank AM, Rusticucci M, Alexander LV, Brönnimann S, Charabi YA, Dentener FJ, Dlugokencky EJ, Easterling DR, Kaplan A, Soden BJ. Observations: atmosphere and surface. InClimate Change 2013–The Physical Science Basis 2013 (pp. 159-254). Cambridge University Press.

Elsen PR, Monahan WB, Merenlender AM. Global patterns of protection of elevational gradients in mountain ranges. Proceedings of the National Academy of Sciences. 2018; 115(23):6004-6009. https://doi.org/10.1073/pnas.1720141115.

Ahmad M, Uniyal SK, Batish DR, Singh HP, Jaryan V, Rathee S, Sharma P, Kohli RK. Patterns of plant communities along vertical gradient in Dhauladhar Mountains in Lesser Himalayas in North-Western India. Science of The Total Environment. 2020; 716:136919. https://doi.org/10.1016/j.scitotenv.2020.136919.

Jabeen N, Kozgar MI, Dar GH, Shawl AS, Khan S. Distribution and taxonomy of genus Aconitum in Kashmir: potent medicinal resource of Himalayan valley. Chiang Mai J. Sci. 2013; 40(2):173-186. http://it.science.cmu.ac.th/ejournal/

Ved D, Saha D, Ravikumar K, Haridasan K. Aconitum chasmanthum. The IUCN Red List of Threatened Species 2015: e.T50126558A79578539. 2015. https://dx.doi.org/10.2305/IUCN.UK.2

Anwar S, Ahmad B, Sultan M, Gul W, Islam N. Biological and pharmacological properties of Aconitum chasmanthum. J Biol Sci. 2003;3(11):989-993.

Dhar U, Kachroo P. Alpine Flora of Kashmir Himalaya. Brittonia. 1983; 35(4):379. https://agris.fao.org/agris-search/search.do?recordID=US201300367748

The Ayurvedic Pharmacopoeia of India—Part I, 1st ed. Ministry of Health and Family Planning, Government of India: New Delhi, India, 2000; 180–182.

Gujree GM, Nawchoo IA, Wafai BA. Meiotic System and Pollination Mechanisms of the Critically Endangered Aconitum chasmanthum Stapf ex Holmes—A Novel Species Endemic to Kashmir Himalayan Region. Int. J. Plant Rep. Biol. 2009;1:153-162.

Rafiq S, Wagay NA, Bhat IA, Kaloo ZA, Rashid S, Lin F, El-Abedin TK, Wani SH, Mahmoud EA, Almutairi KF, Elansary HO. In vitro propagation of Aconitum chasmanthum Stapf Ex Holmes: An endemic and critically endangered plant species of the western Himalaya. Horticulturae. 2021;7(12):586. https://doi.org/10.3390/horticulturae7120586

Rasool G. Medicinal Plants of the Northern Areas of Pakistan: Saving the plants that save us. 1998; pp. 13–15.

Shyaula SL. Phytochemicals, traditional uses and processing of Aconitum species in Nepal. Nepal Journal of Science and Technology. 2011;12:171-178. https://doi.org/10.3126/njst.v12i0.6496

Shinwari ZK, Watanabe T, Rehman M, Youshikawa T. A pictorial guide to Medicinal Plants of Pakistan. KUST. Kohat, Pakistan. 2006; Volume 1:969–8870.

Shrikumar S, Ravi TK. Approaches towards development and promotion of herbal drugs. Pharmacog Rev. 2007; 1(1):180-184.

Khare CP. Indian Medicinal Plants Springer-Verlag Berlin, Germany. 2007.

Rafiq S, Wagay NA, Elansary HO, Malik MA, Bhat IA, Kaloo ZA, Hadi A, Alataway A, Dewidar AZ, El-Sabrout AM, Yessoufou K. Phytochemical screening, antioxidant and antifungal activities of Aconitum Chasmanthum Stapf ex Holmes wild rhizome extracts. Antioxidants. 2022; 11(6):1052. https://doi.org/10.3390/antiox11061052

Gratani L, Meneghini M, Pesoli P, Crescente MF. Structural and functional plasticity of Quercus ilex seedlings of different provenances in Italy. Trees. 2003;17(6):515-521. https://doi.org/10.1007/s00468-003-0269-8

Valladares F, Sanchez-Gomez DA, Zavala MA. Quantitative estimation of phenotypic plasticity: bridging the gap between the evolutionary concept and its ecological applications. Journal of ecology. 2006;94(6):1103-1116. https://doi.org/10.1111/j.1365-2745.2006.01176.x

Gujree GM. *Studies on Reproductive Biology to Develop Conservationn Strategies for Picrorhlza kurrooa Royle ex Benth. and Aconitum chasmanthum Stapf ex Holmes* (Doctoral dissertation, Department of Botany, University of Kashmir, India),2007.

Mir AH, Tyub S, Kamili AN. Ecology, distribution mapping and conservation implications of four critically endangered endemic plants of Kashmir Himalaya. Saudi Journal of Biological Sciences. 2020; 27(9):2380-2389. https://doi.org/10.1016/j.sjbs.2020.05.006.

Hadi A, Singh S, Rafiq S, Nawchoo IA, Wagay NA, Mahmoud EA, El-Ansary DO, Sharma H, Casini R, Yessoufou K, Elansary HO. In vitro propagation of Aconitum violaceum Jacq. ex Stapf through seed culture and somatic embryogenesis. Horticulturae. 2022; 8(7):599. http://dx.doi.org/10.3390/horticulturae8070599

Šťastná P, Klimešová J, Doležal J. Altitudinal changes in the growth and allometry of Rumex alpinus. Alpine Botany. 2012; 122(1):35-44. https://doi.org/10.1007/s00035-012-0099-7.

Kim E, Donohue K. Local adaptation and plasticity of Erysimum capitatum to altitude: its implications for responses to climate change. Journal of Ecology. 2013;101(3):796-805. https://doi.org/10.1111/1365-2745.12077

Scheepens JF, Stöcklin J. Flowering phenology and reproductive fitness along a mountain slope: maladaptive responses to transplantation to a warmer climate in Campanula thyrsoides. Oecologia. 2013; 171(3):679-691. https://doi.org/10.1007/s00442-012-2582-7

Gugger S, Kesselring H, Stöcklin J, Hamann E. Lower plasticity exhibited by high-versus mid-elevation species in their phenological responses to manipulated temperature and drought. Annals of Botany. 2015; 116(6):953-962. https://doi.org/10.1093/aob/mcv155.

Hamann E, Kesselring H, Armbruster GF, Scheepens JF, Stöcklin J. Evidence of local adaptation to fine-and coarse-grained environmental variability in Poa alpina in the Swiss Alps. Journal of Ecology. 2016; 104(6):1627-1637. https://doi.org/10.1111/1365-2745.12628.

Stoecklin J, Armbruster GF. Environmental filtering, not local adaptation of established plants, determines the occurrence of seed-and bulbil-producing Poa alpina in a local flora. Basic and Applied Ecology. 2016; 17(7):586-595. https://doi.org/10.1016/j.baae.2016.06.004.

Sakurai A, Takahashi K. Flowering phenology and reproduction of the Solidago virgaurea L. complex along an elevational gradient on M t N orikura, central J apan. Plant Species Biology. 2017;32(4):270-278. https://doi.org/10.1111/1442-1984.12153.

Hirano M, Sakaguchi S, Takahashi K. Phenotypic differentiation of the Solidago virgaurea complex along an elevational gradient: insights from a common garden experiment and population genetics. Ecology and Evolution. 2017; 7(17):6949-6962. https://doi.org/10.1002/ece3.3252.

Nishizawa T, Kinoshita E, Yakura K, Shimizu T. Morphological variation of the head characters in Solidago virgaurea L. inhabiting three mountains in central Honshu. Journal of Phytogeography and Taxonomy. 2001; 49(2):117-127.

Alexander JM, Edwards PJ, Poll M, Parks CG, Dietz H. Establishment of parallel altitudinal clines in traits of native and introduced forbs. Ecology. 2009; 90(3):612-622. https://doi.org/10.1890/08-0453.1.

Takahashi K, Yoshida S. How the scrub height of dwarf pine Pinus pumila decreases at the treeline. Ecological Research. 2009; 24(4):847-854. https://doi.org/10.1007/s11284-008-0558-1.

Maad J, Armbruster WS, Fenster CB. Floral size variation in Campanula rotundifolia (Campanulaceae) along altitudinal gradients: patterns and possible selective mechanisms. Nordic Journal of Botany. 2013; 31(3):361-371. https://doi.org/10.1111/j.1756-1051.2013.01766.x.

Trunschke J, Stöcklin J. Plasticity of flower longevity in alpine plants is increased in populations from high elevation compared to low elevation populations. Alpine Botany. 2017; 127(1):41-51. https://doi.org/10.1007/s00035-016-0176-4.

Gonzalo-Turpin H, Hazard L. Local adaptation occurs along altitudinal gradient despite the existence of gene flow in the alpine plant species Festuca eskia. Journal of Ecology. 2009; 97(4):742-751. https://doi.org/10.1111/j.1365-2745.2009.01509.x

Khatoon Z, Singh S, Fatima K, Ibrahim M, Ali S, Mallubhotla S. Elevational adaptation and phenotypic plasticity of Codonopsis clematidea in the trans-Himalaya. Discover Plants. 2025; 2(1):281. https://doi.org/10.1007/s44372-025-00361-7

Hadi A, Singh S, Nawchoo IA, Rafiq S, Ali S. Impacts of habitat variability on the phenotypic traits of Aconitum violaceum Jacq. ex Stapf. at different altitudes and environmental conditions in the Ladakh Himalaya, India. Plant Sci. Today. 2022;9:546-554. https://doi.org/10.14719/pst.1734.

Baret S, Maurice S, Le Bourgeois T, Strasberg D. Altitudinal variation in fertility and vegetative growth in the invasive plant Rubus alceifolius Poiret (Rosaceae), on Réunion island. Plant Ecology. 2004;172(2):265-273. https://doi.org/10.1023/B:VEGE.0000026345.67250.d2.

Magray JA, Zargar SA, Islam T, Nawchoo IA. Impact of habitat variability on growth dynamics of Bergenia ciliata (Haw.) Sternb. along an altitudinal gradient in Kashmir Himalaya. Plant Science Today. 2021;9(1):144-149. https://doi.org/10.14719/pst.1367.

Qadir RU, Javid H, Shapoo GA, Wani BA, Magray JA, Nawchoo IA, Gulzar S. Phenotypic variability and resource allocation in Kashmir Sage (Phlomis cashmeriana Royle ex Benth.) in relation to different habitats and altitudes: phenotypic variability of Phlomis cashmeriana Royle ex Benth. in relation to different habitats. Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences. 2022; 59(2):35-47.https://doi.org/10.53560/PPASB(59-2)707.

Bennington CC, McGraw JB. Natural selection and ecotypic differentiation in Impatiens pallida. Ecological Monographs. 1995;65(3):303-324. https://doi.org/10.2307/2937062.

Körner C, Cochrane PM. Stomatal responses and water relations of Eucalyptus pauciflora in summer along an elevational gradient. Oecologia. 1985;66(3):443-455. https://doi.org/10.1007/BF00378313.

Goldstein G, Rada F, Azocar A. Cold hardiness and supercooling along an altitudinal gradient in Andean giant rosette species. Oecologia. 1985;68(1):147-152.https://doi.org/10.1007/BF00379487.

Ligarreto GA, Patiño MD, Magnitskiy SV. Phenotypic plasticity of Vaccinium meridionale (Ericaceae) in wild populations of mountain forests in Colombia. Revista de Biología Tropical. 2011;59(2):569-583.

Bajpai PK, Warghat AR, Yadav A, Kant A, Srivastava RB, Stobdan T. High phenotypic variation in Morus alba L. along an altitudinal gradient in the Indian trans-Himalaya. Journal of Mountain Science. 2015;12(2):446-455. https://doi.org/10.1007/s11629-013-2875-2.

Sultan SE, Bazzaz FA. Phenotypic plasticity in Polygonum persicaria. III. The evolution of ecological breadth for nutrient environment. Evolution. 1993;47(4):1050-1071. https://doi.org/10.1111/j.1558-5646.1993.tb02134.x.

Sultan SE. Phenotypic plasticity and plant adaptation. Acta botanica neerlandica. 1995;44(4):363-383. https://doi.org/10.1111/j.1438-8677.1995.tb00793.x

Menzel A. Phenology: its importance to the global change community. Climatic change. 2002; 54(4):379. https://doi.org/10.1023/A:1016125215496.

Rathcke B, Lacey EP. Phenological patterns of terrestrial plants. Annual review of ecology and systematics. 1985; 179-214. https://www.jstor.org/stable/2097047.

Marquis RJ. Phenological variation in the neotropical understory shrub Piper arielanum: causes and consequences. Ecology. 1988; 69(5):1552-1565. https://doi.org/10.2307/1941653.

Gross RS, Werner PA. Relationships among flowering phenology, insect visitors, and seed-set of individuals: experimental studies on four co-occurring species of goldenrod (Solidago: Compositae). Ecological monographs. 1983;53(1):95-117. https://doi.org/10.2307/1942589.

Barry RG. Mountain weather and climate. InMountain Weather and Climate, Third Edition 2008 (pp. 1-506). https://doi.org/10.1017/CBO9780511754753.

English-Loeb GM, Karban R. Consequences of variation in flowering phenology for seed head herbivory and reproductive success in Erigeron glaucus (Compositae). Oecologia. 1992; 89(4):588-595. https://doi.org/10.1007/BF00317168.

Ollerton J, Lack A. Relationships between flowering phenology, plant size and reproductive success in shape Lotus corniculatus (Fabaceae). Plant ecology. 1998;139(1):35-47. https://doi.org/10.1023/A:1009798320049.

Wafai BA. Studies on reproductive biology of some endangered north west Himalayan medicinal herbs as a prelude to their ex situ conservation. Journal of the Indian Botanical Society. 2005;84:88-106. https://cir.nii.ac.jp/crid/1573950400969630464

Fig. 1 Map depicting collection sites and study area of *Aconitum chasmanthum* Stapf ex Holmes

Fig. 2 Threats faced by *Aconitum chasmanthum* Stapf ex Holmes in its natural habitat (a) high altitude road construction material and destroying the natural population and even making it more susceptible to landslides (b) Long dry spells drying out the populations (c) habitat fragmentation by high altitude road construction (d) larvae feeding on the seed pods and seeds destroying its sexual potential (e) aphids (*Macrosiphum* spp.). feeding on floral parts (f) larvae feeding on floral parts.

Fig. 3 Phenogram showing phenology of *Aconitum chasmanthum* Stapf ex Holmes in 11 different populations across Kashmir Himalaya during 2021.

Fig. 4 Morphology characteristics of *Aconitum chasmanthum* Stapf ex Holmes (a) habit (b) habitat (c) inflorescence (d) seed pods (e) seeds (f) sprouted rhizomes

Fig. 5 Linear regression analysis between several morphological features of *Aconitum chasmanthum* Stapf ex Holmes (a) plant height vs elevation (b) plant height vs basal pedicel length (c) plant height vs basal leaf length (d) plant height vs flower number(e) plant height vs leaf number (f) morphological attributes of *A. chasmanthum*

Fig. 6. Box plot depicts the interquartile range; centre horizontal range represents the median. Line extending out of the box indicated the upper and lower quartile. Black coloured points represent the outlier of 11 morphological characters of in 11 populations of *Aconitum chasmanthum* Stapf ex Holmes

Fig. 7 Phenotypic plasticity index for 11 morphological characters of *Aconitum chasmanthum* Stapf ex Holmes (Plant height (PH), Fresh rhizome length (FRL), Fresh rhizome girth (FRG), Basal petiole length (BPL), Basal leaf length (BLL), Basal leaf width (BLW), Apical leaf length (ALL), Apical leaf width (APW), Pedicel length (PL), Flower number (FN), Leaf number per plant (LN).

Fig. 8 Scattering plot demonstrating Pearson's correlation matrix for quantitative phenotypic traits among different populations of *Aconitum chasmanthum* Stapf ex Holmes (*** $p < 0.000$, ** $p < 0.001$, * $p < 0.01$)

Fig. 9 Principal component analysis (PCA) of morphological characteristics of *Aconitum chasmanthum* Stapf ex Holmes across different study sites. Plant height (PH), Fresh rhizome length (FRL), Fresh rhizome girth (FRG), Basal petiole length (BPL), Basal leaf length (BLL), Basal leaf width (BLW), Apical leaf length (ALL), Apical leaf width (APW), Pedicel length (PL), Flower number (FN), Leaf number per plant (LN).

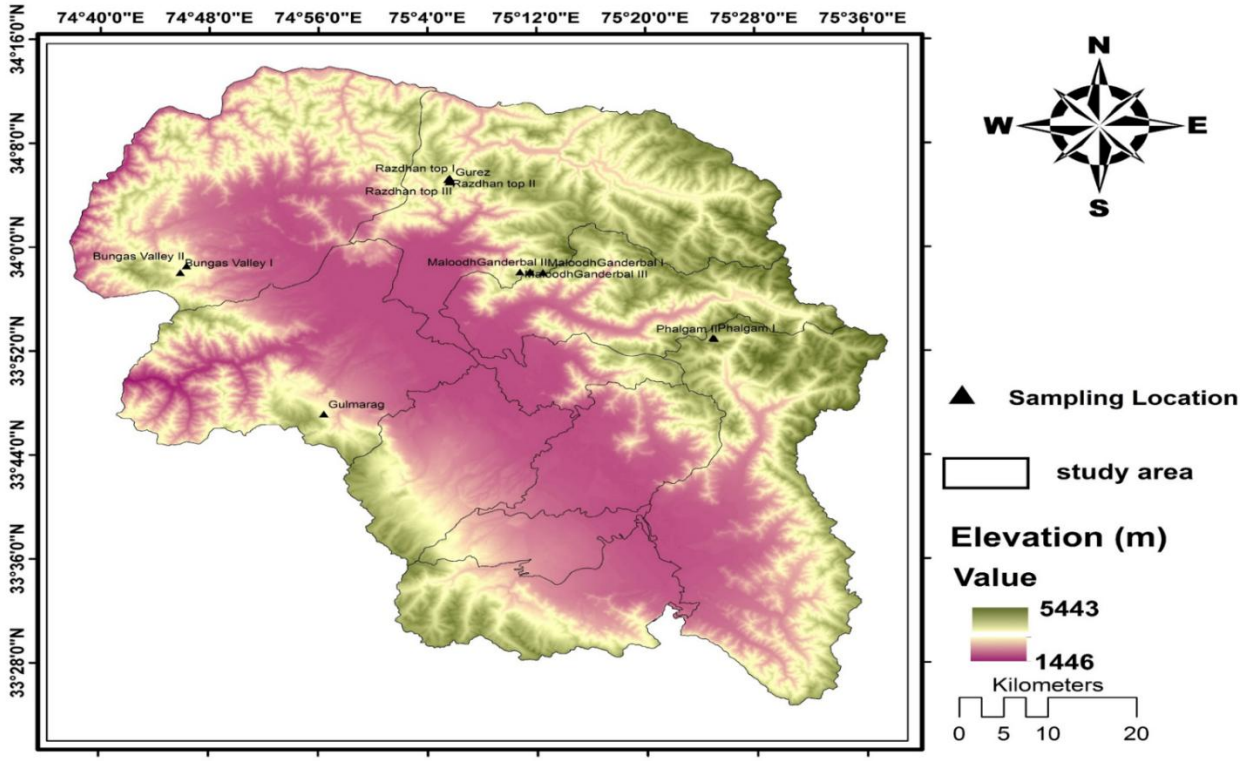


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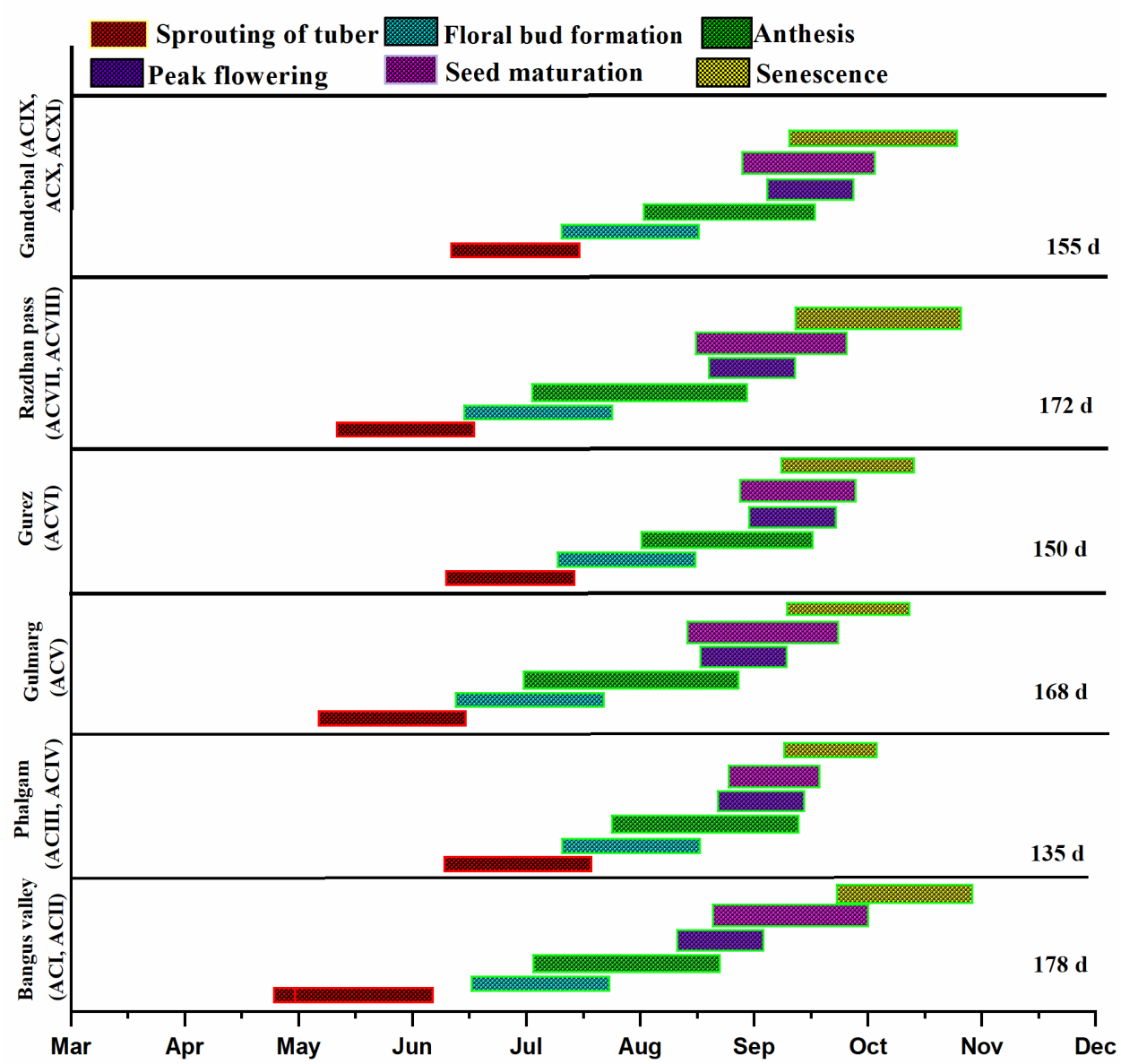


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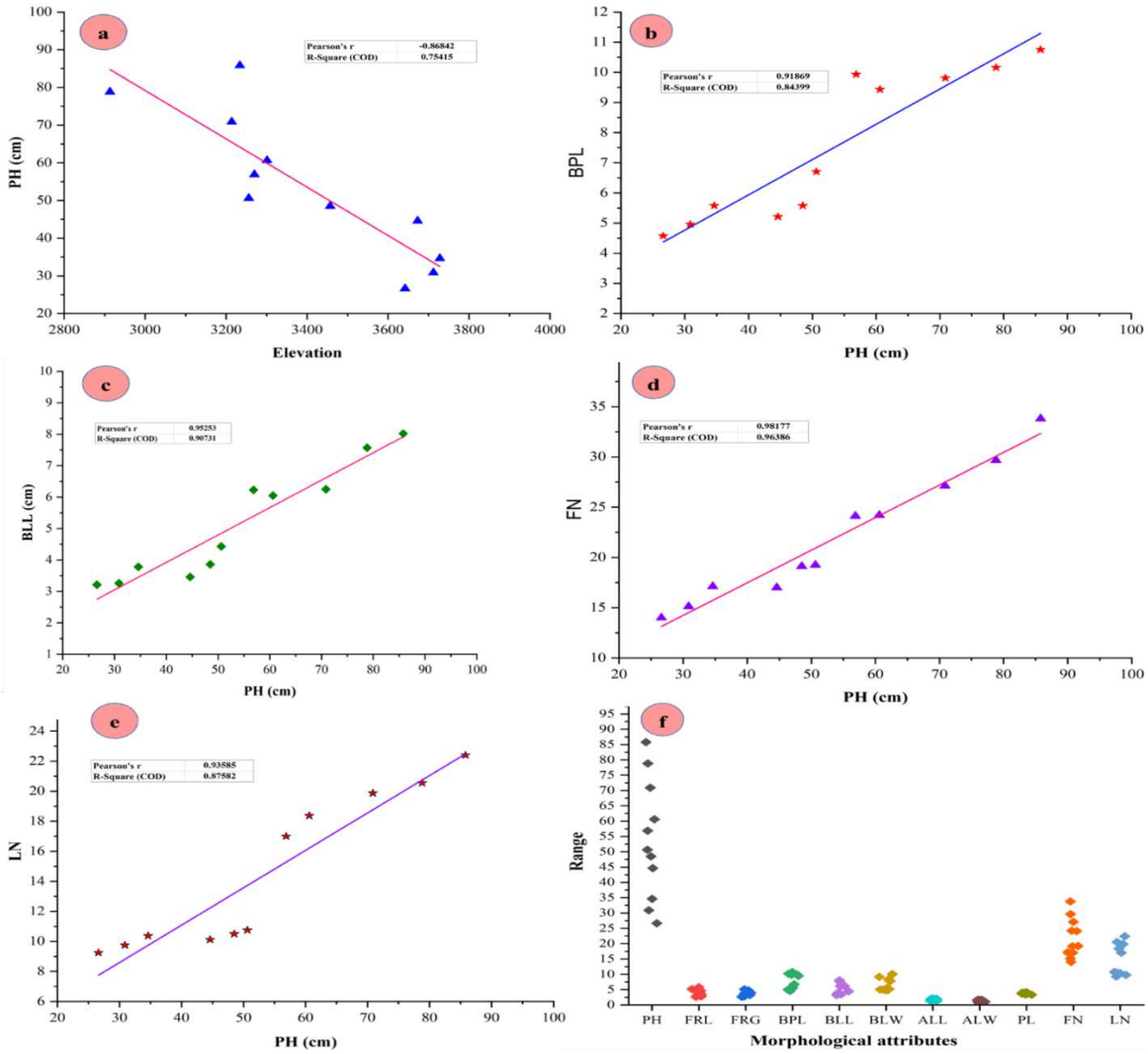


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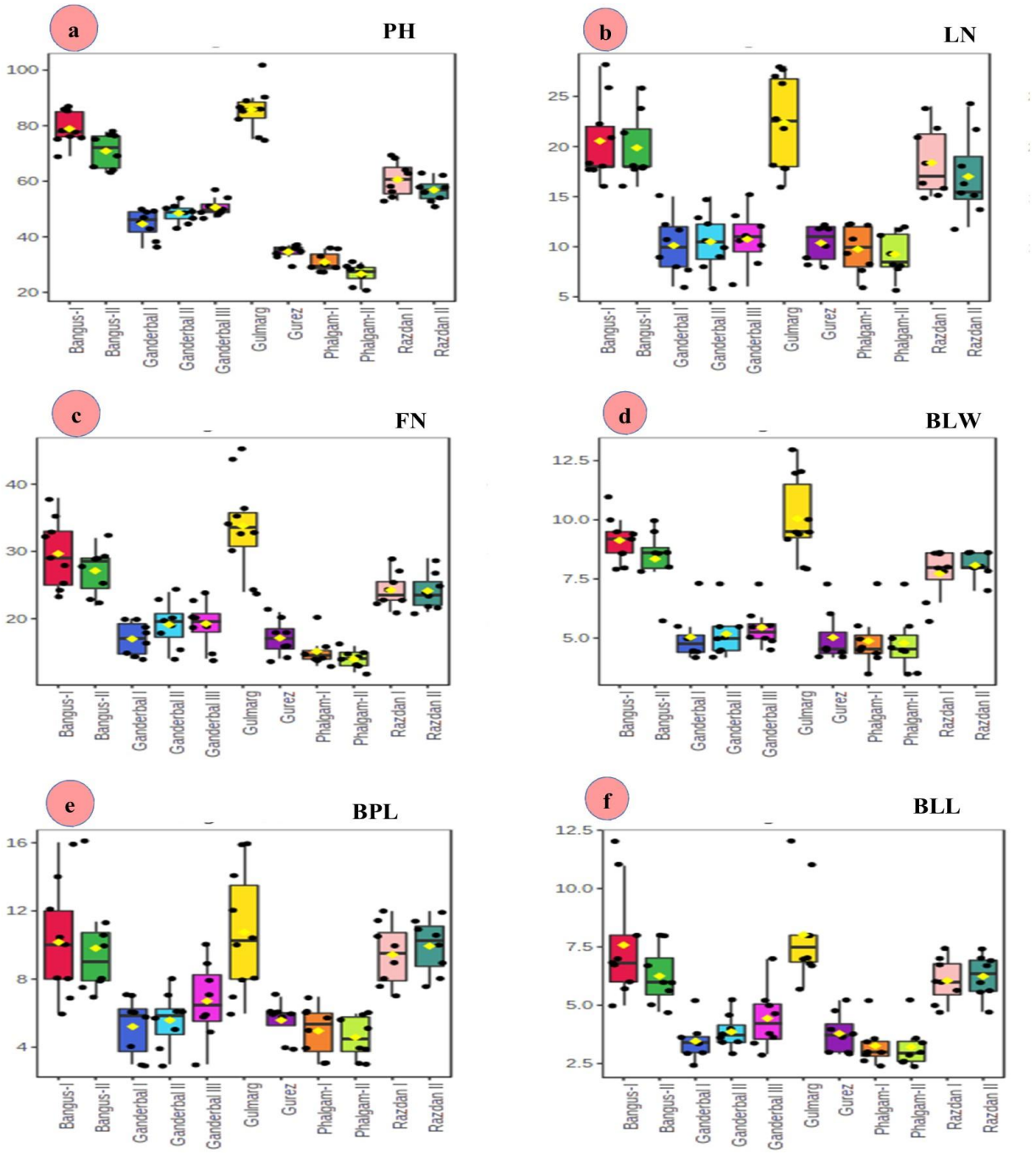


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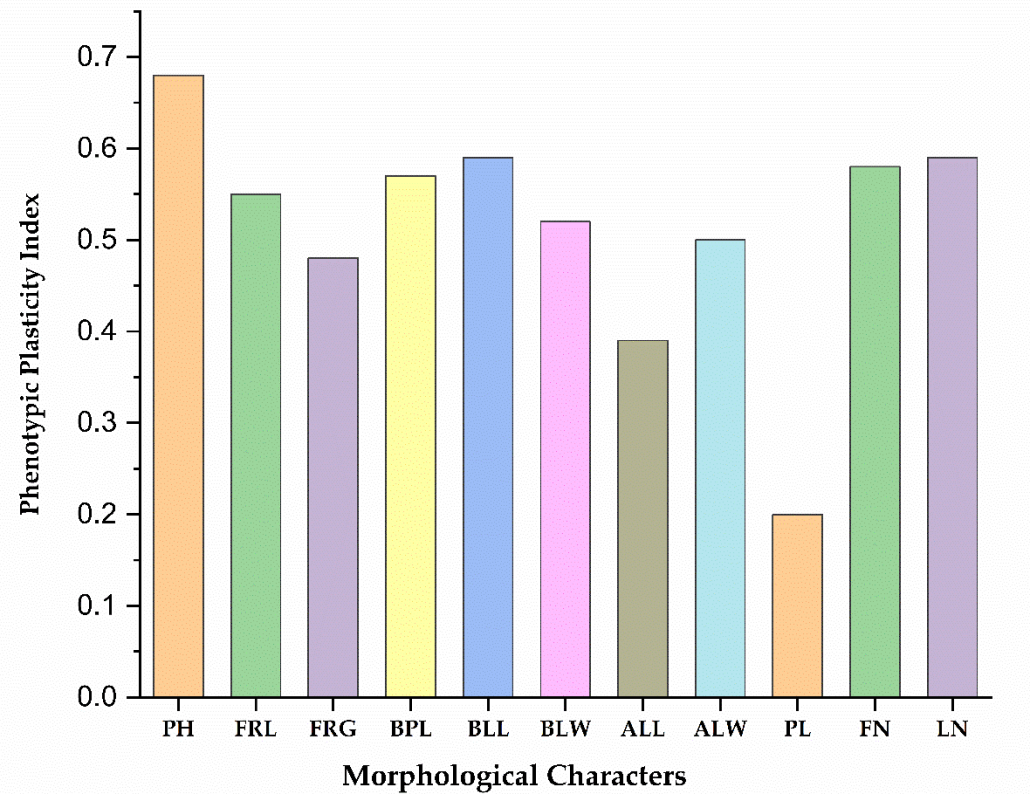


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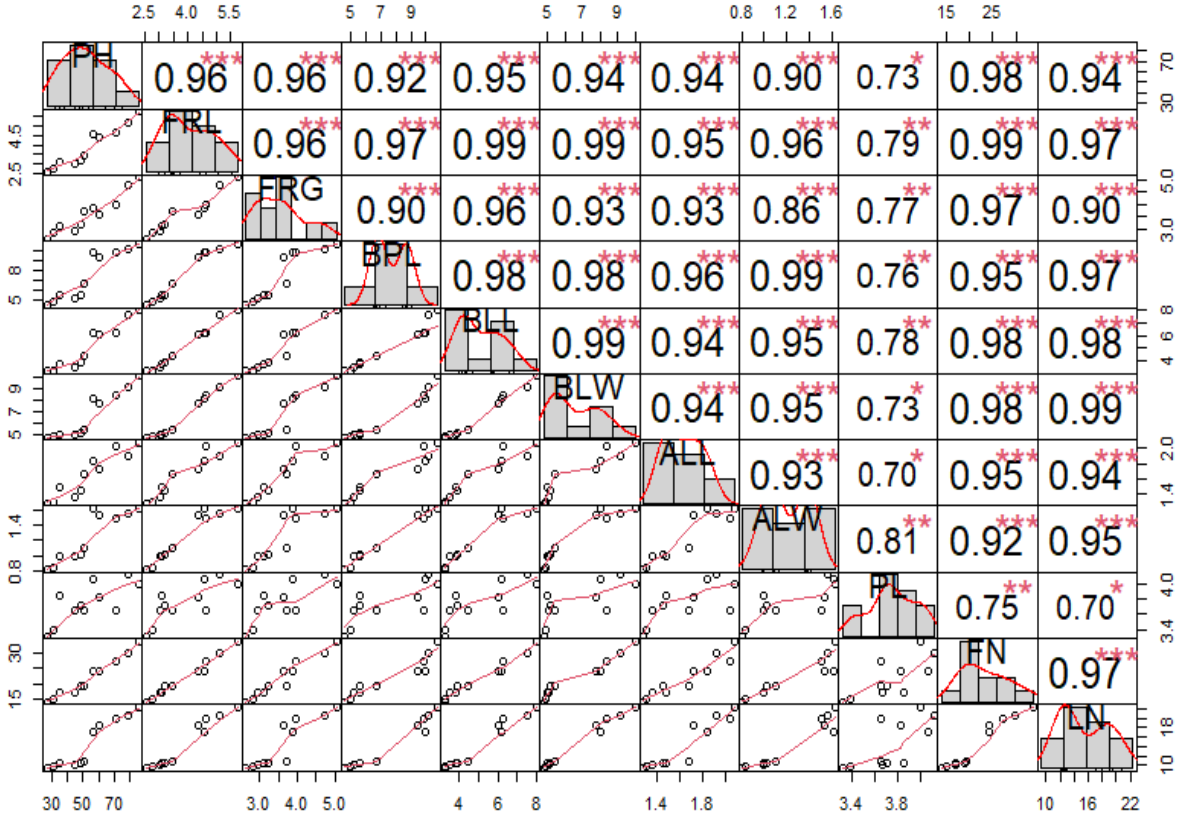


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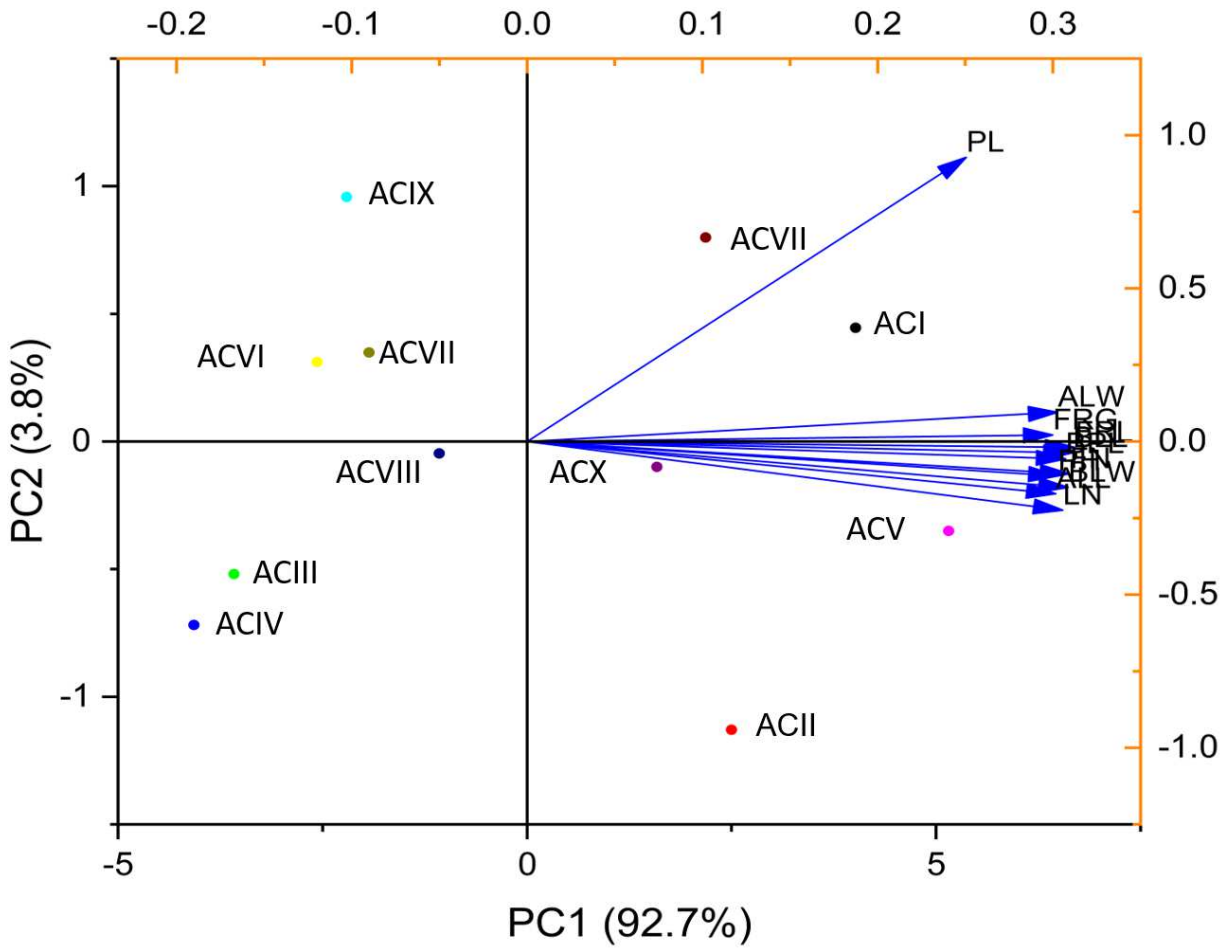


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