



RESEARCH ARTICLE

Impact of habitat variability on growth dynamics of *Bergenia ciliata* (Haw.) Sternb. along an altitudinal gradient in Kashmir Himalaya, India

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Abstract

Bergenia ciliata (Haw.) Sternb. is an important medicinal plant of the Himalayan region. Phenotypic attributes of a particular plant species varies along different altitudes in order to adapt and to overcome the changeable and stressful conditions. A number of environmental factors such as mean temperature, precipitation, soil characteristics, radiation intensity etc. changes with altitudinal gradient and thereby affect the morphological pattern of a plant species. The present study was undertaken to reveal the impact of the elevational gradient and habitat variability on the morphological features of the selected species. Under different environmental conditions the species exhibited enormous variability in its phenotypic traits. The plants were shorter at high altitude site, Gulmarg while the plants of low altitude site, Kashmir University Botanical Garden (KUBG) were taller and more vigorous. A significant decrease in the plant height, inflorescence length, leaf length, leaf breadth and petiole length occurred with increasing altitude. Principal component analysis (PCA) revealed that the habitat of KUBG and Ferozpora (Tangmarg) proved relatively better for the growth of *B. ciliata*. The regression analysis revealed positive correlation between plant height and traits like inflorescence length, leaf length, leaf number and thus predicting a direct impact of plant height on other traits. Our findings present a comprehensive account on the variability of phenotypic characteristics, in relation to the environmental conditions of this valuable medicinal plant species.

Keywords

Himalayan region, habitat variability, altitudinal gradient, phenotypic attributes

Introduction

Bergenia ciliata (Haw.) Sternb. (family Saxifragaceae) is perennial herbs up to 50 cm tall, succulent, distributed in temperate Himalayan region (from Kashmir to Nepal) (1). This family comprising of 30 genera and 580 species mostly distributed in the cold and temperate regions (2). The genus *Bergenia* comprises of 6 species distributed in the temperate Himalayas and Central and East Asia. *Bergenia ciliata* is commonly known as hairy *Bergenia* and is found throughout temperate Himalaya region (from Kashmir, Nepal, southeast Tibet to Afghanistan) (3) at an altitude of 800–3000 m asl (3, 4). In Jammu and Kashmir, *B. ciliata* is locally known as *Zakhmehayat* (5), *Batweyaa*, *Pashanbhed* (6). The variability in growth and position of resource accumulating parts such as rhizomes, leaves are crucial for adjust-

ment of plants to resource accessibility (7). Under severe conditions, plants can adjust themselves either by adapting genetically to the local environmental conditions or by exhibiting phenotypic plasticity (8). For plants phenotypic plasticity is of utmost importance as they are immobile and have to thrive in the fluctuating local conditions. It also acts as a window to adjust rapidly to the changing environmental conditions (9, 10). At higher altitudes phenotypic plasticity is believed to occur more regularly, enabling the alpine plants to adapt to the temporally variable environment (11, 12). Although plasticity is beneficial but can have neutral or negative impacts on fitness of plant species (13). Plants alter important physiological processes such as photosynthetic rates, gaseous exchange (14) and morphological traits (15, 16) in response to environmental factors. Decrease in plant length along altitudinal gradient is the most visible change in plant morphology (17).

Bergenia ciliata is an important medicinal plant of western Himalaya, used in treating various diseases (18). The plant species shows many important biological activities such as antioxidant, anti-inflammatory, antitussive, antiviral, antiulcer, hypoglycemic and toxicological activities (19 - 21). It is a potent source of flavonoids, saponins, alkaloids, amino-acids and carbohydrates (22). Bergenin and its glycosides, (+)-Catechin, Gallic acid and leucocyanidin, Paashaanolactone, β -Sitosterol -Afzelechin are some of the important phytochemicals of *B. ciliata* (23). Rhizome and root is an effective to combat chronic venereal diseases (4). The plant species is commonly found growing in moist and shady slopes particularly on rock crevices (24). Taxonomically, this plant species is a large scrambling shrubs with thick and fleshy rhizome, growing upto 0.31 m - 1.0 m in height. Leaves are simple with ciliated margins. The height and branching pattern, however depends upon the genetic makeup and environmental factors of a particular site (Phenotype = Genotype \times Environment) (25). The scape is stout, having pentamerous corymbose inflorescence. Sepals 5 (gamosepalous), petals 5 (polypetalous), stamens are 10 in number (5 larger and 5 smaller), pollen tri colpate, smooth. Fruit is a round shaped capsule containing numerous seeds. Seed are minute, elongated smooth and dark brown to blackish in colour. The flowering and fruiting period of *B. ciliata* extends from February to August (24, 26). The present study was carried out to understand degree of variation in phenotypic traits along the altitudinal gradient. This study aimed at formulating strategies for cultivation and sustainable use of wild populations and to find the environments

that are most suitable and prolific for the growth of *B. ciliata*.

Materials and Methods

The present study involved the use of robust methods and approaches in the field (both in control and natural habitats) and laboratory to monitor, record and understand the phenotypic variability and reproductive strategies of the species. The data on various morphometric characters for revealing the aspects of the phenotypic variability were recorded from March 2015 to October 2016.

Survey, collection and documentation

Different habitats of Kashmir Himalaya (India) were extensively explored and surveyed to select the specific study sites across this region. In order to study the variability in phenotypic characteristics of *B. ciliata* along the altitudinal gradient, three sites (populations) were selected along with a control site at Kashmir University Botanical garden (KUBG). The map (Fig. 1) shows the

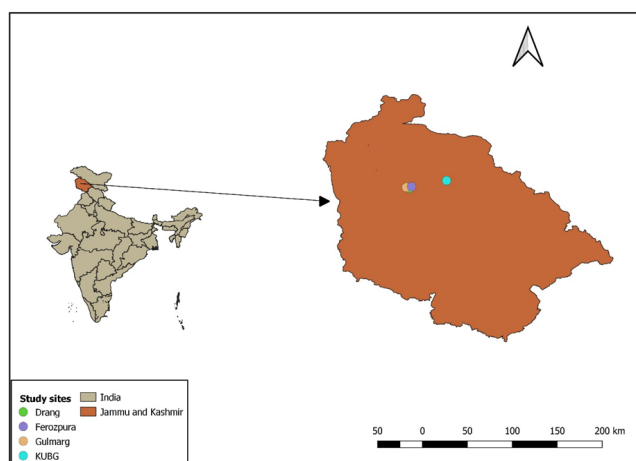


Fig. 1. Map showing study sites of *Bergenia ciliata* (Haw.) Sternb. in Kashmir valley. (QGIS 3.16).

geographical location of selected sites. During the present study, the marked individuals of selected plant species across different study sites were monitored on regular basis from March 2015 to October 2016. Geo-coordinates (latitude and longitude) along with altitude and also the habitat of four study sites are listed in Table 1. Plant samples (10 plants) from each site were collected at mature, flowering stage. The vegetative propagules of selected plant species were transplanted in the KUBG (control site) to study the morphological variations.

Table 1. Geo-coordinates and habitat characteristics of the selected sites

Sl. No.	Location	Altitude (m asl)	Latitude (N) and Longitude (E)	Habitat	Threat Factor
1.	Gulmarg	2590	34° 02' 54.4" N 74° 20' 49.8" E	Moist Open Slope	Over exploitation, overgrazing, landslide
2.	Drang	2235	34° 2' 87.0" N	Sunny to partly shady Slope	Over exploitation, overgrazing, landslide and habitat destruction
3.	Ferozpora (Tangmarg)*	2120	34° 3' 22.6" N	Shady slope	Over exploitation, overgrazing, landslide and habitat destruction.
4.	KUBG*	1595	34° 7' 57.17" N 74° 50' 15.19" E	Open Field	Nil

*KUBG - Kashmir University Botanical Garden.

Species morphology and phenotypic variability

The selected sites were visited continuously at regular intervals of 10 days following standard procedures. All the parameters including morphological traits, habitat type, phytosociology, breeding behaviour and collection of plant samples were recorded at the peak flowering stage of the plant. The plants were analyzed for morphological traits like plant height, number of leaves per plant, mean leaf length per plant, mean leaf breadth per plant, mean petiole length per plant, rhizome length, root length and inflorescence length.

Statistical analysis such as mean, standard Deviation, linear regression for understanding correlation between phenotypic traits across altitudinal gradient to recognize the most suited growth sites of the species, and PCA (Principal component analysis) for analyzing phenotypic traits in relation to different habitat conditions were carried out using Origin Pro 2019b 64 bits software. From each population, data was recorded for 10 plants for comparing the variability in phenotypic characteristics. The photographs were clicked using Samsung mobile having 16 mpxl camera.

Results and Discussion

Plants and environment have an intricate relationship, a range of environmental factors and stresses challenge the plant to adapt and survive with increase in altitudinal gradient. In order to compete and overcome these stress conditions plants alter their biochemical and morphological attributes (25, 27). The disparity in phenotypic characters with varying altitude indicates plasticity and evolutionary changes in these traits, influencing performance and survival of populations existing across altitudinally or climatically variable conditions (28).

Bergenia ciliata exhibits a significant variability in its phenotypic traits under different environmental conditions. This phenotypic variability was observed in four selected sites viz. Gulmarg (2590 m asl), Drang (2235 m asl), Ferozpora (Tangmarg) (2120 m asl) and Kashmir University Botanical Garden (KUBG) Srinagar (1595 m asl) as a control site. The morphological traits that were assessed for phenotypic variability are plant height, number of leaves, mean leaf length, mean leaf breadth, mean petiole length, rhizome length, root length and inflorescence length per plant (Table 2). Fig. 2 shows the morphological features of *B. ciliata*. The selected phenotypic traits shows significant varia-



Fig. 2. *Bergenia ciliata* (Haw.) Sternb. A. habit; B – C. inflorescence; D. habitat; E. seeds.

bility along with altitudinal gradient. The plant height ranges from 9.97 ± 4.33 to 42.57 ± 14.86 cm, number of leaves per plant are 3.00 ± 0.81 to 4.0 ± 1.24 cm. The mean leaf length per plant is 6.29 ± 1.02 to 13.27 ± 4.05 cm. The mean leaf breadth per plant was 3.48 ± 1.07 to 8.96 ± 2.96 cm and mean petiole length per plant turned out to be 1.99 ± 0.44 to 4.46 ± 2.14 cm. The rhizome length ranged from 4.89 ± 1.10 to 5.73 ± 1.74 cm. The root length ranges from 13.54 ± 4.92 to 17.21 ± 5.53 cm whereas inflorescence length turned out to be 5.26 ± 2.30 to 24.21 ± 7.28 cm. Most of the phenotypic traits showed a negative correlation with the altitude i.e. they depicted a decreasing trend with increasing altitude.

Morphological traits analyzed vary significantly across the selected populations, viz., Gulmarg, Drang and Ferozpora (Tangmarg) and KUBG. The plant height varies across the different populations. There is an increase in the height of plant in shady environment as seen in site

Table 2. Phenotypic variability of *B. ciliata* across the different study sites

Phenotypic traits	Populations			
	Gulmarg*	Drang	Ferozpora (Tangmarg)	KUBG*
Plant height (cm)	$9.97 \pm 4.33^{**}$	13.10 ± 3.89	13.88 ± 4.05	42.57 ± 14.86
No. of Leaves per Plant	3.00 ± 0.81	4.00 ± 1.54	4.00 ± 1.13	5.00 ± 1.24
Mean leaf Length per plant (cm)	6.29 ± 1.02	8.34 ± 1.16	8.42 ± 1.29	13.27 ± 4.05
Mean leaf breadth (cm)	3.48 ± 1.07	5.53 ± 1.38	5.60 ± 1.08	8.96 ± 2.96
Mean petiole length (cm)	1.99 ± 0.44	2.24 ± 0.57	2.33 ± 0.72	4.46 ± 2.14
Rhizome length (cm)	4.89 ± 1.10	5.65 ± 1.51	5.85 ± 1.63	5.73 ± 1.74
Root length (cm)	13.54 ± 4.92	18.01 ± 4.24	18.13 ± 4.36	17.21 ± 5.56
Inflorescence length (cm)	5.26 ± 2.30	8.33 ± 2.05	9.24 ± 2.11	24.21 ± 7.28

*Kashmir University Botanical Garden, **Mean \pm SD

Ferozpora (Tangmarg) compared to the plants exposed to direct sun light. As compared to the natural populations, plants transplanted at control site (KUBG) exhibited the highest values for nearly all the morphological characters. Dendrogram showing clustering of study sites, exhibits similar phenotypic variations in different traits of plant species as shown in Fig. 3. The variations in phenotypic traits

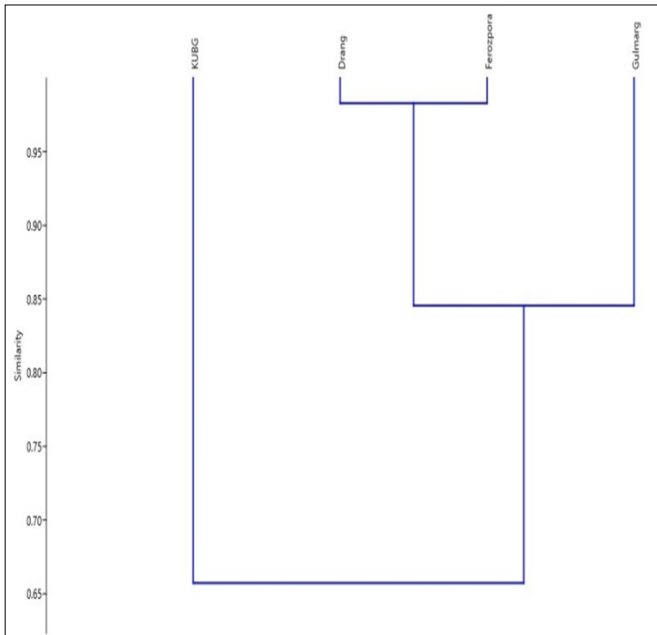


Fig. 3. Dendrogram (cluster analysis) showing the similarity among different selected study sites.

across natural populations and KUBG were very significant while as Drung and Ferozpora (Tangmarg) were not very significant which may be attributed to least differences in their overall environmental conditions. A positive correlation between plant height and inflorescence length ($r^2 = 0.9674$), leaf length and plant height ($r^2 = 0.8803$), leaf number and plant height ($r^2 = 0.0492$) were observed as shown in Fig. 4 (A-H). In Fig. 5, Principle Component Analysis (PCA) reveals that the population growing at higher alti-

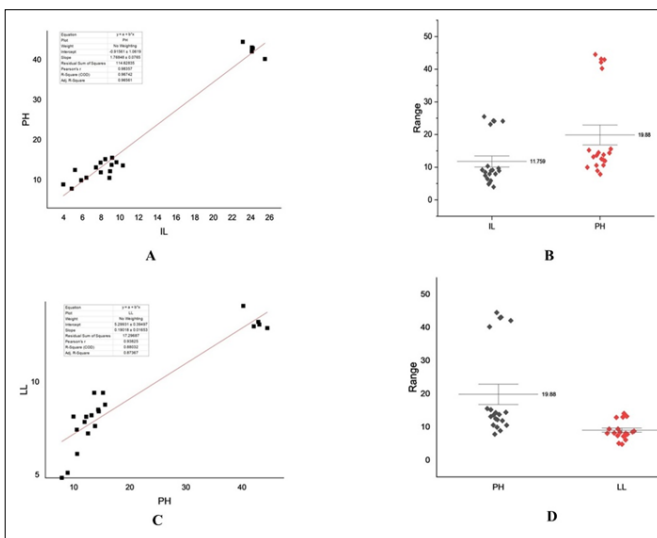


Fig. 4 (A-D). Regression analysis and scale interval between various morphological traits of *Bergenia ciliata* (Haw.) Sternb.

tude (Gulmarg) shows decrease in size of phenotypic traits and thus separated the population of Gulmarg from the other populations. However the population growing at

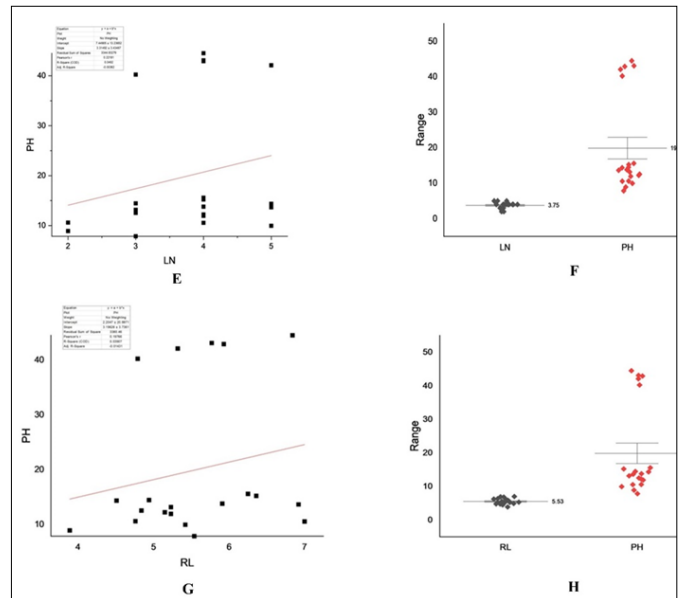


Fig. 4 (E-H). Regression analysis and scale interval between various morphological traits of *Bergenia ciliata* (Haw.) Sternb.

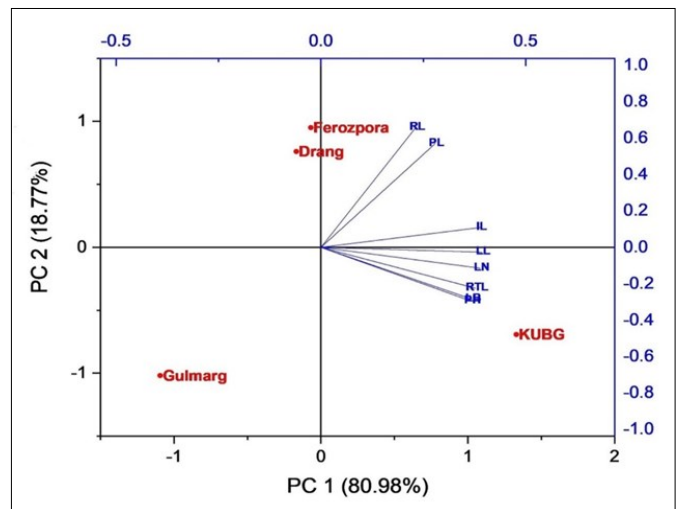


Fig. 5. Principal Component Analysis (PCA) of morphological characteristics of *Bergenia ciliata* (Haw.) Sternb. across the different study sites. PH. plant height; LB. leaf breadth; RL. rhizome length; PL. petiole length; IL. inflorescence length; LL. leaf length; LN. leaf number; RTL. root length.

Ferozpora (Tangmarg) possesses the average plant height of 13.88 ± 4.05 cm in comparison with the populations growing at Drang and Gulmarg having the plant height of 13.10 ± 3.89 cm and 9.97 ± 4.33 cm, respectively. The scale interval (Fig. 6) shows the mean and range of selected phe-

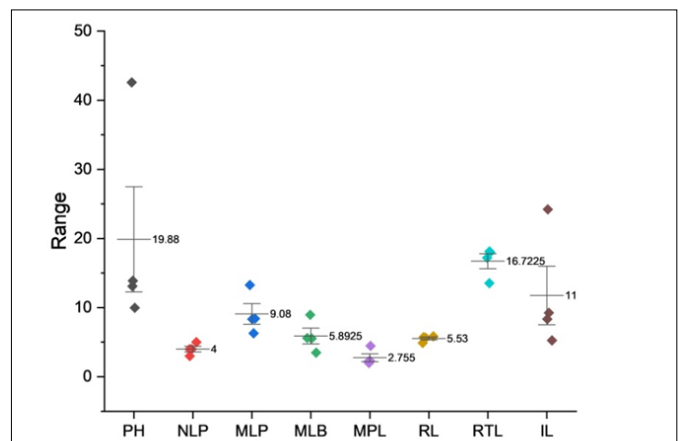


Fig. 6. Scale interval showing the mean and range of all phenotypic traits of *Bergenia ciliata* (Haw.) Sternb.

notypic traits. The shady environment favors the plant species to attain the maximum height as it has to compete for light. This supports the findings of (29). Similar findings were reported by several workers (30–34) stated that the decrease in plant height along with altitudinal gradient is advantageous for the species as it prevents the plant from strong winds. There is increase in leaf dimensions in plants growing at lower altitudes (8.42 ± 1.29) as compared to those growing at higher altitudes (6.29 ± 1.02). The obtained results are in conformity with those of (35) who reported that leaves dimensions generally decrease with increase in altitude.

Conclusion

The present study revealed that *Bergenia ciliata* growing at different altitudes exhibited differences in plant morphology, architecture and reproductive ecology. The results depicted a wide range of suitable habitats for the growth of *B. ciliata*. The species exhibits significant phenotypic variability in morphological traits *i.e.*, plant height, number of leaves per plant, rhizome length inflorescence length etc. in natural as well as transplant populations along altitudinal gradient. It can be inferred from the present study that variation in environmental conditions proved to have an enormous impact on the growth dynamics and development of *B. ciliata*. It can be suggested from the present study that the plants growing at low altitudes were comparatively much more diverse and vigorous in respect of the various morphological features. There is variability in the morphological attributes such as height, leaf number, inflorescence length etc. and seed set along the altitudinal gradient. These variations in morphological parameters and seed formation may be due to the impact of various environmental factors, seasonal variations and competition for resources or herbivory.

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Authors contributions

This work was carried out in collaboration between the authors. Author JAM collected the primary data and wrote the first draft of manuscript and. Author SAZ edited the first draft of manuscript. Author TI prepared map and managed the analysis of the data. Author IAN edited and designed the final draft of manuscript. All authors read and approved the final manuscript

Compliance with ethical standards

Conflict of interest: Authors declare that there is no com-

peting interest.

Ethical issues: None.

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