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Phyto-ecological analysis of *Phytolacca acinosa* Roxb. assemblages in Kashmir Himalaya, India

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Phyto-ecological studies are essential in understanding community structure, organization and their response to changes in other environmental factors. In this study we analyzed the phytosociological and soil characteristics of *Phytolacca acinosa* communities and their correlation. 110 quadrats were laid across ten randomly selected sites in Kashmir Himalaya, India. Soil analysis was done using standard protocols. Overall, 161 species were recorded, belonging to 128 genera and 49 families. The species richness (SR) ranges from 27 to 83. Highest IVI was recorded for *Poa angustifolia* (60.06) and least for *Berberis lycium*, *Abies pindrow*, *Plectranthus ragosus*, and *Ailanthus altissima* (0.37 each). *P. acinosa* showed 100% random associations with other plant species. Soil properties varied significantly across the selected sites. Significant positive correlation was found between species richness (SR), Organic matter (OM) (r = 0.79), Organic carbon (OC) (r = 0.79) and Shannon–Wiener index (H) (r = 0.92). Nitrogen content also showed positive correlation with SR and H. Floristic composition of *P. acinosa* assemblages was governed by soil properties and habitat characteristics of sampling sites. Areas with highest floral diversity had high soil fertility while areas with low soil fertility possess lower diversity and need restoration. The knowledge may prove helpful in management of these habitats, boost conservation and mitigate the effects of changing climate.

KEYWORDS

climate change, community composition, Kashmir Himalaya, soil chemistry, species diversity

Introduction

Study of vegetation structure dynamics is a vital aspect of ecology that assists in understanding the function and overall structure of a community. Phytosociology or vegetation analysis is the science that deals with the study of the plant assemblages (communities), their characteristics, composition, classification, distribution, and relationships among species. Its primary goal is to delimit and characterize vegetation types based on the whole species (floristic) composition (Dengler, 2016). Phytosociological studies are important in understanding the population dynamics, habitat, species interaction and vegetation structure of an ecosystem (Collins et al., 2020). The vegetation of an area can be classified based on physiognomy and functional combination or on its component species that discriminate the physical appearance of vegetation (Mumshad et al., 2021). Plant communities are formed by those species which share the structural and floristic characteristics at certain level of environmental tolerance. Various biotic and abiotic factors of a region influence the plant population and vegetation heterogeneity (Jiao et al., 2019; Ocon et al., 2021). Furthermore, edaphic factors and topography complexity impact plant performance, vegetation composition and diversity (Chin and Kupfer, 2020). The phyto-ecological studies are essential in understanding the interrelationship between soil, environment and vegetation structure of a specific region. These investigations are vital in ascertaining the ecological status of species in a community (Ray and George, 2009), besides understanding the species diversity, organization of communities and in selecting valuable species from plant communities (Abinaya and Paulsamy, 2015; Wani Z. A. et al., 2022). The functional capacities of an ecosystem as well as its components are evaluated for ecological assessment. This involves assessment of phytosociological parameters (diversity, abundance, frequency, and important value index) of each species and anthropogenic threats to their habitat that may affect the functional and structural integrity of an ecosystem (Manoj et al., 2012).

Kashmir Himalaya, a scenic landscape of Indian sub-continent, an integral part of the Himalayan biodiversity hotspot. Himalayan region harbors stupendously diverse repository of plants with enormous economic and medicinal value (Aryal et al., 2018; Tali et al., 2019). This biodiversity is sustained by the steep climatic gradient characterized in Mountainous range of Himalaya (Rawal et al., 2018; Rana et al., 2021). In Himalayan ecosystems, floral diversity has a crucial role in maintaining ecological, functional integrity and serving indispensable ecosystem services that have enormous scientific utility (Ahmed et al., 2020). Apart from anthropogenic pressures that include deforestation, land cover change and urbanization, mountain ecosystems are also very sensitive to changing climate which eventually leads to the biodiversity loss (Khan S. M. et al., 2012; Paudel et al., 2018; Yadav et al., 2021). Therefore, for maintaining biodiversity and soil fertility, effective management strategies are mandatory. For the benefit of nature and humans, the United Nations Decade on Ecosystem Restoration (2021–2030) has emphasized restoration and protection of ecosystems across all continents. Healthy ecosystems have the ability to alleviate the effects of changing climate and prevent the loss of biodiversity. Phyto-ecological studies are important in understanding the relationship between vegetation, environment and plant responses toward changing climate (Chawla et al., 2012). Vegetation surveys and documentation will assist in monitoring and evaluating climate change that are vital for conservation and management initiatives (Malfasi and Cannone, 2020).

Phytolacca acinosa Roxb. (Phytolaccaceae) is a perennial herb distributed across Himalaya from Hazara to Bhutan. It is native to Himalaya, east and southeast Asia including Myanmar, China, Taiwan, Bhutan, Japan, Tibet, Vietnam, Manchuria, India, and Korea mostly growing along roadsides, inside forests and forest margins at the elevation of 500–3400 m (POWO., 2022). *P. acinosa* has immense medicinal importance and is widely used as a diuretic in Chinese folk medicine system and treatment of various diseases such as swelling, edema, indigestion, eye disorder, body ache, and sores (Ma et al., 2017; Basnet and Kalauni, 2020). *P. acinosa* contains many phytochemicals including tannins, flavonoids, polyphenol, triterpenoids, flavones, saponins, tannic and phenolic compounds (Lin et al., 2018; Ma et al., 2019; Tao et al., 2020). It also exhibits substantial antibacterial, antifungal, antiviral and anti-inflammatory activities (He et al., 2004; Manzoor et al., 2017; Abekura et al., 2019). Keeping in view the medicinal importance of the plant species the phytosociology in relation to soil and ecological parameters were carried out. The data generated will not only be helpful for the management of the species but also the habitats as well, which may prove helpful in conservation of this valuable plant species as well help in restoration of these habitats and mitigate the impacts of climate change.

The aim of our study was to address the following specific questions; (i) the composition of plant assemblages associated with *Phytolacca acinosa* in the Kashmir Himalaya (ii) soil parameters of the study sites (iii) variability of the ecological parameters of associated communities of the *P. acinosa* and (iv) the correlation between phytosociological and soil parameters in *P. acinosa* assemblages across the selected sites of Kashmir Himalaya.

Materials and methods

Study area

The current study was conducted in Kashmir Himalaya, India, situated between 32°20’ to 34°50’ N latitude and 73°55’ to 75°35’ E longitude (Tali et al., 2015) encompassing an area of around 15,948 sq. km. The region is a part of the northwest Himalaya in India and comprises of a deep oval shaped valley, bounded by high mountain ranges; the Lesser or Middle Himalaya, known as the Pir Panjal Range, separates the Valley from the Jammu region in the south and southwest, while the Greater Himalaya separates it from the Ladakh region in the north and east (**Figure 1**). The altitudinal gradient of the valley ranges from 1500 to

1800 m (asl), whereas the average elevation of the adjacent mountains' ranges from 3000 to 4000 m, with Kolahoi (5420 m) (Romshoo et al., 2020) being the highest peak. Climate of this region exhibits resemblance with continental-Mediterranean type found along temperate latitudes and is characterized by well-defined seasonality. The mean annual temperature of the region varies from a maximum of 35°C in summer to minimum of −10°C during winter (Zaz et al., 2019) and receives an annual precipitation of roughly 1200 mm predominantly in the form of snow (Romshoo et al., 2020). The vegetation of the area is temperate; subalpine and alpine type harboring enormous floristic diversity.

Selection of sites

Extensive field surveys were carried out across Kashmir Himalaya and 10 sites were selected based on the presence, abundance and availability of the natural populations of *P. acinosa* (**Figure 1**). The selected sites vary visually in vegetation structure and composition. The geo-coordinates and habitat characteristics are given in **Table 1**.

Vegetation sampling

The phytosociological studies were carried out during 2020–2021 across selected sites using the quadrat method (Curtis and McIntosh, 1950). The vegetation diversity was analyzed by using random sampling technique to give the best representation of the floristic composition. A total of 10 study sites (with 110 quadrats) were selected for vegetation sampling. At each site, 8–10 quadrats of 3 m × 3 m size with *P. acinosa* at center of each quadrat were randomly laid out for sampling. Additional quadrats were laid to distinguish possible unrecognized communities. The shape of quadrat was primarily square but at some instances was modified as per requirement to obtain a homogeneous and representative portrayal of vegetation, e.g., rectangular plots along water streams (Walentowski et al., 2018). Phytosociological characteristics i.e., abundance, frequency, density, relative abundance, relative frequency, relative density, and Importance Value Index (IVI) were a determined at every site for *P. acinosa* along with constituent plant species (Noreen et al., 2019; Kamran et al., 2020). Distribution levels were noted for other associated species available in the study area. The species richness (SR) was calculated as the total number of species present in a sampling site. Moreover, species diversity was determined using diversity indices such as Simpson's index (1/D) (Simpson, 1949), Jaccard's index (J) (Chao et al., 2005), and Shannon–Wiener index (H) (Shannon and Weaver, 1963). All the collected specimens were identified with the help of experts and by perusal the existing literature and online flora (POWO., 2022).

Soil sampling and analysis

For soil analysis, composite soil samples were collected from rhizosphere up to a depth of 15cm from each selected site in triplicates, correctly labeled, air dried in laboratory, and then sieved to remove gravel and debris (Khan et al., 2017; Iqbal et al., 2021). The soil properties—available nitrogen (N), potassium (K), phosphorus (P), soil organic carbon (OC), organic matter (OM), and soil pH were analyzed. The soil samples were analyzed at Soil Testing Laboratory of State Agriculture Department, Lal Mandi, Srinagar, Jammu and Kashmir, India.

The pH of soil was estimated in 1:5 soil–water suspensions using a digital pH meter (Khan W. et al., 2012). Likewise, OC in soil was assessed by rapid titration method of Walkley and Black (1934). At each study site, other chemical parameters of soil including available N, K, and P were analyzed using already set methodology of Subbiah and Asija (1956); Black (1968) (flame photometric method); and Olsen et al. (1954) (spectrophotometer method), respectively. Soil organic matter (OM) was computed by multiplying a factor of 1.724 to soil OC (Davies, 1974).

Statistical analysis

All the collected data was analyzed to evaluate the phytosociological attributes of each species, their relationships and effect of various soil properties on the vegetation attributes of the selected area. For further analysis the data related to plant assemblages at all sites (quadrats) was sorted in MS EXCEL as per software requirements. To appraise the impact of edaphic factors on species composition and distribution pattern, the species and soil data were analyzed using correlation analysis in Origin pro 2021b software (version 9.0). The data matrix of species was subjected for cluster analysis to visualize the similarity among the study sites. Bray–Curtis index was employed to estimate the degree of similarity in species composition between the ten selected sites (Ismail and ELawad, 2015) using PAST software (version 4.09). The similarity dendrogram obtained from the result of cluster analysis was plotted. The plant (vegetation) data was also quantitatively analyzed for the determination of frequency, density, abundance as per Mishra et al. (2017); and Curtis and McIntosh (1950) and important value index (IVI) of *P. acinosa* and associated species at each study site. The IVI of each species was computed by adding up the relative frequency, relative density, and relative abundance following Phillips (1959). Data regarding composition and structure of the natural habitats harboring populations of *P. acinosa* was recorded across all the selected sites. The sampling was carried out during the flowering period and the data pertaining to *P. acinosa* assemblages along with the associated plant species was collected from 10 study sites (**Table 1**). The community composition was analyzed

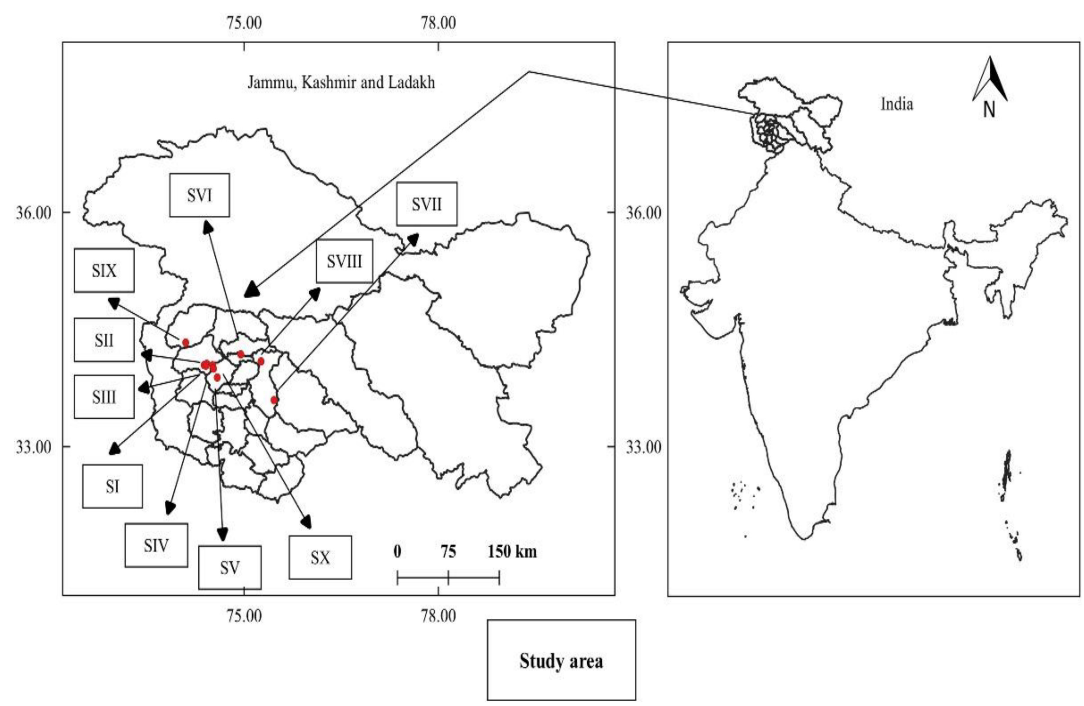

FIGURE 1
Map showing the study area and sampling sites in Kashmir Himalaya, India. (SI–Tangmarg; SII–Gulmarg; SIII–Drung; SIV–Gogaldara; SV–Doodhpathri; SVI–Dara Harwan; SVII–Daksum; SVIII–Pahalgam; SIX–Bangus; SX–Khag).

Table 1 Geo-coordinates, altitude and habitat characteristics of the study sites across Kashmir Himalaya, India.

Study sites	Latitude (N)	Longitude (E)	Altitude (m asl)	Habitat
Tangmarg (SI)	34.06085°	74.42472°	1,950	Open rocky slope
Gulmarg (SII)	34.04557°	74.38441°	2,700	Partial shady and slope
Drung (SIII)	34.03783°	74.41106°	2,250	Shady, inside forest
Gogaldara (SIV)	34.04317°	74.51425°	2,400	Shady slope
Doodhpathri (SV)	33.88613°	74.58712°	2,600	Open slope
Dara, Harwan (SVI)	34.18201°	74.94989°	2,150	Rocky slope, both open and shade
Daksum (SVII)	33.59575°	75.46383°	2,900	Shady slope and little moist
Pahalgam (SVIII)	34.09216°	75.26322°	2,800	Partial shady slope
Bangus (SIX)	34.33333°	74.09972°	2,500	Partial shady along roadside
Khag (SX)	34.00011°	74.52829°	2,000	Open along roadside

using cooccur package (version 4.0.3) in which co-occurrence data matrix (presence/absence) was envisaged by probabilistic hypergeometric co-occurrence model employed in R Core Team (2020) (Griffith et al., 2016). To extract the species pairings and associated probabilities, we use the *prob table()* function to retrieve the results element of the cooccur object.

Results

In the present study, 161 plant species were recorded belonging to 128 genera and 49 families (**Supplementary Material 1**, **Figure 2**). Out of these plant species, herbs were dominant with 84.47% followed by trees (7.45%), shrubs (5.59%), climber (1.24%), and Fern (1.24%). However, the contribution of different families to the floristic diversity was disproportionate: only 7 families contributed half (50%) of the species pool, while the remaining 50% of the species were contributed by the rest of the 41 families. In terms of the species number, Asteraceae was found as the largest family with 25 species followed by Lamiaceae (13 species), Poaceae and Rosaceae (10 species each), Polygonaceae (8 species), Fabaceae and Caryophyllaceae (7 species each), Ranunculaceae (7 species). There were 21 families represented by a single species recorded at different sites of Kashmir Himalaya (**Figure 2**). The natural vegetation of a particular region reflects the interaction amongst the associated fauna and flora, edaphic and other environmental factors. The calculated IVI values were used to assign the dominance of species. The highest IVI was recorded for *P. angustifolia* and least for *B. lycium*, *A. pindrow*, *P. ragosus*, and *A. altissima.* Based on IVI, *Poa angustifolia* (IVI 60.06), *C. dactylon* (53.60), *P.* pratensis (16.70)*, U. dioica* (30.73)*, C. iberica* (25.04)*, T. repens* (15.17), *G. nepalense* (24.58), *F. nubicola* (14.08), *and P. aviculare* (19.45) were the dominant species in *P. acinosa* communities across different sampling sites. *P. acinosa* secured highest and lowest IVI of 11.33 and 4.82 in site II and site X, respectively. Habit-wise, herbaceous flora was dominant with 136 species followed by arboreal flora (12 species), shrubs (9 species), climbers (2 species) and ferns (2 species).

The plant species richness ranged from 27 to 83 and differed between different study sites. *C. dactylon* and *U. dioica* were the most common species found across most of the sites. The Shannon-Wiener diversity index (H) was highest at (SVIII)- (4.12). Khag (SX) reported the lowest value of Shanon (H) (2.68), Simpson (1/D) (0.81) and Jaccard's (J) index (0.9), respectively. The results of current study highlighted variations in species richness (SR) and plant community composition associated with the variability in soil properties across the sampling sites. The highest species richness was found at site SVII (Daksum) while the lowest i.e., 27 species were listed at site SX (Khag).

The phytosociological and soil parameters of selected sites

Site SI (Tangmarg)

The site SI was relatively less diverse having a low value of shannon-weiner index (0.88). Out of 31 plant species, *Cynodon dactylon* with IVI 53.60 was the dominant one followed by *Urtica dioica* (IVI 30.73) and *Centaurea iberica* (25.04). *Berberis lycium* and *Stipa sibirica* were the rare species having IVI 2.25 and 2.77, respectively. *P. acinosa* recorded an IVI of 10.55. The species composition reflects the presence of 30 herbs and a single tree species. The soil at site I was less acidic (pH–6.68) (**Table 2**). The average OC content at Site I was 3.57% and OM was 6.16%. The value of N, P, and K was 0.02%, 132.43 and 596.59 kg ha^{-1}, respectively.

Site SII (Gulmarg)

The vegetation analysis of the *P. acinosa* communities at Site SII (Gulmarg) revealed rich species diversity. This site has high species richness of 68, with *C. dactylon* (IVI 17.18) being the dominant species followed by *P. pratensis* (IVI 15.40) while *R. webbiana* (IVI 1.24) was recorded as rare species. *P. acinosa* secured the lowest IVI of 4.82 at Gulmarg. Herbs represent 89.71%, shrubs and trees 4.41% each and climbers 1.47% of the total vegetation. The average pH (acidity) and OC of the soil was 5.71 and 6.55%, respectively. Besides, the mean value of N, P, and K were calculated as 0.04%, 234.83 kg ha^{-1} and 443.15 kg ha^{-1}, respectively.

Site SIII (Drung)

The Site SIII has an altitude of 2200m asl and *P. angustifolia* having IVI 60.06 was the dominant species followed by *C. dactylon* (IVI 44.03) while *R. canina* and *R. fruticosa* each with IVI 2.43 were rare species. A total of 32 species were recorded. Among these 3.13% were trees, 9.38% shrubs, and 87.50% herbs. The value of the soil pH was 6.32 (**Table 2**) indicating slightly less acidic nature of soil. Further, the mean value of soil chemical properties including K, P, N, OM and OC was 568.59 kg ha^{-1}, 100.8 kg ha^{-1}, 0.04, 6.92, and 4.02%, respectively.

Site SIV (Gogaldara)

The plant community of sampling Site SIV is represented by 49 species. *C. dactylon* and *P. angustifolia* were the dominant species whereas *E. canadensis* was rare species based on calculated IVI. Vegetation was a blend of herbs (95.92%) shrubs (2.04%) and trees (2.04%). The mean soil pH and OC content was 6.05 and 6.58%, respectively. Moreover, the mean value of P and N in soil was recorded as 146.20 kg ha^{-1}, and 0.045%, respectively.

Site SV (Doodhpathri)

At Doodhpathri, 33 species were found and *T. repens* was the dominant, followed by *U. dioica*. The lowest IVI of 2.47 was calculated for *A. acuminata*. The vegetation was composed of 32 herbs and a single shrub. The soil of Site V was less acidic having pH (6.19). The mean OC and OM content present in soil was 2.24% and 3.86%, respectively. Soil of this site also had maximum average value of 619.36 kg ha^{-1} for K (**Table 2**).

Site SVI (Dara)

Site SVI harbors unique and ample floristic diversity with species richness of 68 with herbs, shrubs and trees accounting for 82.35, 8.82, and 8.82%, respectively. *U. dioica* was the dominant species of this area followed by *V. odorata*. The calculated IVI of *P. acinosa* was 4.68. This site has lower content of OM (5.40%) and OC (3.13%) in soil (**Table 2**). Furthermore, the average P, K, and N content at this site was 74.84 kg ha^{-1}, 385.21 kg ha^{-1}, and 0.03%, respectively.

Site SVII (Daksum)

Site SVII (Daksum) has a high species diversity having Shanon-weiner index of 3.99 and registered the highest species richness (83). Based on calculated IVI, *P. aviculare* (19.45) and *P. pratensis* (16.70) were the dominant species of this area. *A. pindrow*, *B. lycium*, *P. ragosus* had lowest IVI. The area is dominated by herbs (90.36%) followed by trees (6.02%)

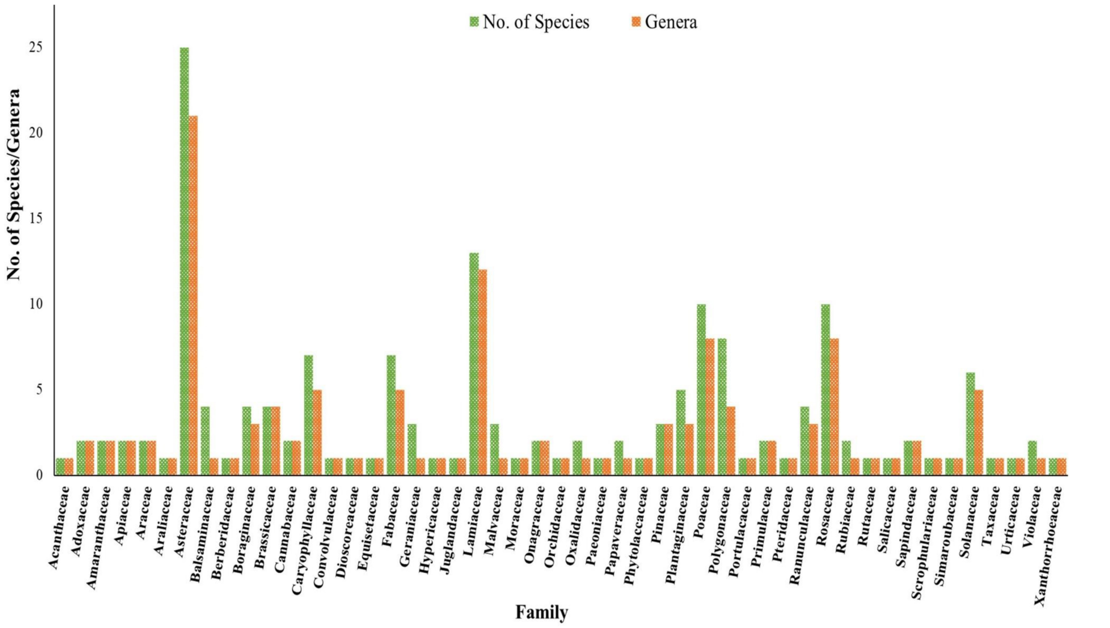

FIGURE 2
Number of species and genera present in different families recorded across study sites.

Table 2 Soil chemical properties and floral diversity parameters of selected study sites in Kashmir Himalaya (OC–organic carbon, OM–organic matter, N–Nitrogen, P–phosphorus, K–potassium; SR–species richness, H–Shanon-weiner index, J–Jaccard's index of evenness, 1/D–Simpson's index).

Site	pH	OC (%)	OM (%)	N (%)	P (Kgha^{-1})	K (Kgha^{-1})	SR	H	J	1/D
SI	6.68 ± 0.02*	3.57 ± 0.02	6.16 ± 0.03	0.02 ± 0.012	132.43 ± 12.37	596.59 ± 37.89	31	3.01	0.88	0.92
SII	5.71 ± 0.02	6.55 ± 0.19	11.30 ± 0.02	0.04 ± 0.004	234.83 ± 12.43	443.15 ± 16.48	68	4.05	0.96	0.98
SIII	6.32 ± 0.02	4.02 ± 0.02	6.92 ± 0.06	0.04 ± 0.003	100.80 ± 9.59	568.59 ± 22.63	32	2.9	0.84	0.91
SIV	6.05 ± 0.05	6.58 ± 0.02	11.34 ± 0.10	0.045 ± 0.001	146.2 ± 11.98	543.20 ± 19.54	49	3.62	0.94	0.97
SV	6.19 ± 0.01	2.24 ± 0.01	3.86 ± 0.02	0.032 ± 0.002	154.78 ± 5.67	619.36 ± 23.73	33	3.35	0.96	0.96
SVI	6.92 ± 0.05	3.13 ± 0.02	5.40 ± 0.03	0.03 ± 0.004	74.84 ± 8.76	385.21 ± 11.05	68	3.92	0.93	0.98
SVII	5.54 ± 0.03	12.39 ± 0.09	21.36 ± 0.02	0.05 ± 0.007	177.63 ± 13.24	605.55 ± 38.33	83	3.99	0.9	0.97
SVIII	5.89 ± 0.08	10.59 ± 0.02	18.26 ± 0.09	0.08 ± 0.030	77.88 ± 6.41	552.53 ± 17.17	76	4.12	0.95	0.98
SIX	6.76 ± 0.07	6.21 ± 0.02	10.71 ± 0.02	0.05 ± 0.002	43.25 ± 8.35	289.78 ± 10.05	39	3.51	0.96	0.96
SX	6.46 ± 0.05	1.16 ± 0.01	2.00 ± 0.02	0.03 ± 0.004	111.10 ± 9.74	473.76 ± 15.88	27	2.68	0.81	0.91

*Mean ± SD.

and shrubs (3.61%). The soil was most acidic having pH of 5.84 and quite rich in chemical properties with highest average value of OM and OC content (12.39% and 21.36%), respectively (Table 2). The average value calculated for P, K and N were also high (177.63 kg ha^{-1} and 605.55 kg ha^{-1}, and 0.05%, respectively).

Site SVIII (Pahalgam)

Phytosociological studies at site SVIII (Pahalgam) revealed the presence of second highest number of species (76) associated with the *P. acinosa* comprising of 96.05% herbs, 2.63% trees and 1.32% shrubs. *T. repens* (IVI 12.38) and *I. heterantha and R. pseudoacacia* (IVI 0.43 each) were the dominant and rare species, respectively. The soil of site VIII had second lowest average pH of 5.89 and highest nitrogen content of 0.08%. The soils also share a rich proportion of OC, OM and K content (10.59%, 18.26%, and 552.53 kg ha^{-1}, respectively) (Table 2).

Site SIX (Bangus)

The Site SIX has a species richness of 39 mostly comprised of herbs (97.44%) and shrubs (2.56%). The highest IVI was recorded for *C. dactylon* and lowest IVI for *S. chrysanthemoides, A. accuminata and T. farfara.* The average calculated pH, OC and OM of the soil was 6.76, 6.21% and 10.71%, respectively.

The site had the average N content of 0.05% and recorded the lowest value of P content (43.25 kg ha^{-1}) (**Table 2**).

Site SX (Khag)

At Site SX the plant community was represented by lowest number of species having species richness of 27. As per IVI calculated, *U. dioica* was the dominant species followed by *P. pratensis* while as *A. pindrow*, *R. pseudoacacia* and *P. wallichiana* were rare species. The Vegetation found in this site was a blend of all the growth forms: herbs (59.23%), trees (25.93%) and shrubs (14.81%). The soil had nitrogen content of 0.74% and average calculated pH and OM was 6.76. The site has lowest average value of OM (2.00%) and OC (1.16%) (**Table 2**). Moreover, the value recorded for N, P and K was 0.03%, 111.10 kg ha^{-1} and 473.76 kg ha^{-1}, respectively.

The present study revealed that plant community composition and species distribution pattern is considerably regulated by the amount and availability of soil nutrients. The correlation plot (**Figure 3**) indicated that species richness is positively correlated with OC, OM, N, P, Shannon diversity (H) and Simpson diversity (1/D) (r = 0.79, 0.79, 0.58, 0.24, 0.92, and 0.79, respectively), but the resultant correlation was significant only between species richness and OC, OM, Shannon diversity and Simpson index ($p < 0.05$). Similarly, species richness is negatively correlated with pH ($r = -0.56$), but the correlation was non-significant. In addition, positive correlation was found between Shannon diversity index and Simpson diversity index ($r = 0.95$; $p < 0.05$). A negative corelation was found between potassium and species diversity. SR increased significantly with increasing OC and OM content of soils.

Community composition and association

On the basis of community composition, a total of 161 plant species were reported to be associated with *P. acinosa.* Out of the 12880 species pair combinations, 8006 pairs (62.16%) were eliminated from the analysis as expected co-occurrence was < 1 and 4874 pairs were analyzed. The findings show that the majority of the classifiable species combinations were truly random. The significant non-random associations were mostly positive (524 positive compared to 153 negative).

Cooccurrence Summary:

Species	Plots	Positive	Negative	Random	Unclassifiable	Non-random (%)
161.0	110.0	524.0	153.0	4197.0	0.0	13.9

The plant of interest (*Phytolacca acinosa*) shows 100% random associations with other species i.e., observed frequency of co-occurrence is not significantly different and roughly equal to expected. Visualizations of all pairwise combinations of species and their co-occurrence signals (positive, negative, and random) (**Figure 4**). The plot removes any species with non-significant negative or positive correlations, and then ranks the remaining species from the most negative to the most positive relationships (left to right).

Cluster analysis

The cluster analysis revealed highest similarity of 71.39% among SVII (Daksum) at 2900 m asl and SVIII (Pahalgam) at 2800 m asl. On the other hand, site III (Drung) at 2200 m asl inside coniferous forest m asl and site X (Khag) 2000 m asl in disturbed roadside habitat showed the least similarity (37.01%) (**Figure 5**).

Discussion

During this study, total 161 plant species from 128 genera belonging to 49 plant families were documented from the selected sites of Kashmir Himalaya, India. The dominant families in the region were Asteraceae and Lamiaceae, followed by Rosaceae. The studies are in accordance with Altaf et al. (2021) and Nafeesa et al. (2021), who also recorded the dominance of these families in Kashmir Himalaya. The dominance of the Asteraceae and Lamiaceae families in the Himalayan region is due to their larger ecological amplitude, high adaptive capacity, larger seed output, and presence of different reproductive strategies in diverse environmental conditions (Haq et al., 2021; Sofi et al., 2022; Wani I. A. et al., 2022).

The IVI gives an idea of socio-ecological interaction of species' and dominance pattern in a population (Wani I. A. et al., 2022). Across the study sites, analysis of IVI unveiled diverse species combinations with distinct dominants and co-dominants. The IVI of the constituent species exhibited considerable degree of variation ranging between 0.37 to 60.06. *P. angustifolia, P. pratensis, C. dactylon, U. dioica, C. iberica, T. repens, G. nepalense, F. nubicola and P. aviculare* have scored highest IVI (more dominant) reflecting their better adaptive mechanism to the conditions of the region (Ge et al., 2005; Shaheen et al., 2012). The majority of dominating species in the selected sites belonged to the Poaceae family. The higher seed vigor, germination, survivability and different means for vegetative reproduction assist these species for their stronger perpetuation (Ismail and ELawad, 2015). The studied species, *P. acinosa* has IVI ranging between 4.82 (Gulmarg)-11.33 (Khag) reflecting that this species had less perpetuation in the community of Gulmarg while better adaptation in Khag than the other associated species. Community characteristics of plants are highly impacted by the pressure exerted by overgrazing, trampling and varying environmental conditions.

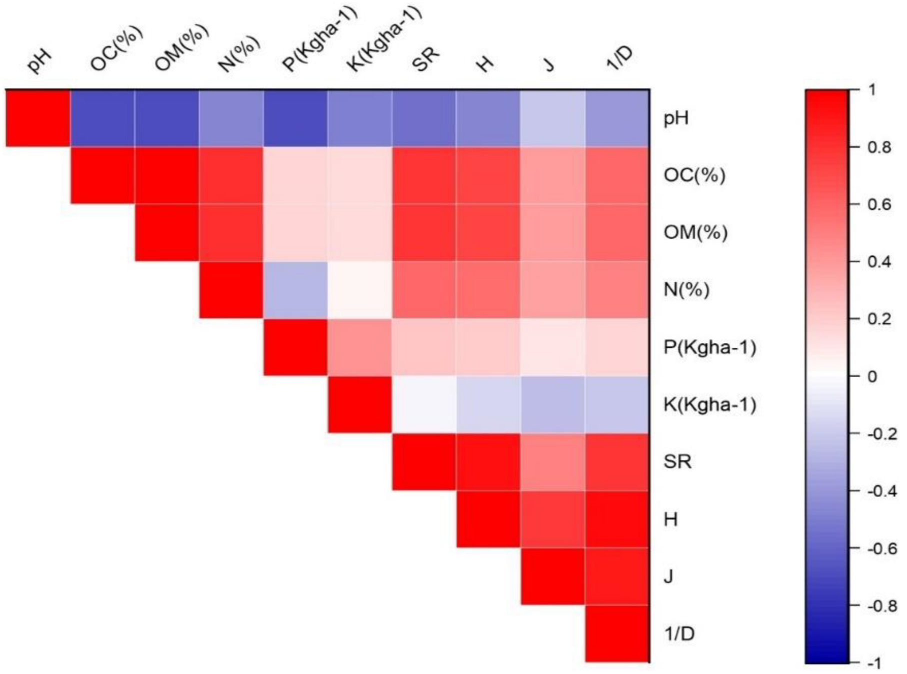

FIGURE 3
Correlation plot between vegetation and soil parameters. Statistical significance $p < 0.05$.

These differences in IVI across the sites may be attributed to surrounding environmental conditions and the anthropogenic activities which have already been reported from this area (Ganie et al., 2019). The IVI value of any species is an outcome of prevailing micro environmental conditions as well (Abinaya and Paulsamy, 2015).

The soil across sampling sites was acidic in nature with pH ranging between 5.54 to 6.92. Gairola et al. (2012), also suggested that for steady supply of nutrients the pH of forest soils should be slightly acidic. It has also been reported that the acidic nature of forest soils may be due to the basic cation uptake of by tree roots (Fujii et al., 2018). The pH of soil differed significantly across the study sites ($F = 1.976$, $p = 0.051$). This change in pH may be attributed to altitudinal differences among sites (Wani I. A. et al., 2022). There is significant negative correlation ($r = -0.7$, $p < 0.05$) between available P content and pH at the study sites (**Figure 3**). This is because crystalline and amorphous forms of Al and Fe couple with inorganic P compounds depending on pH of soil (Hedley et al., 1982). Organic matter (OM) is a major constituent of the forest floor supporting microbiological diversity and guarantees a long-term supply of nutrients through decomposition. OM provides a significant portion of soil carbon (C) and regulates soil characteristics (Mishra et al., 2018). Significant variation in both OC ($F = 8244.371$, $p < 0.05$) and OM ($F = 45985.584$, $p < 0.05$) was found across the study sites, with highest values at SVII (Daksum). This is consistent with the results depicted by Powers and Schlesinger (2002) who reported that soil carbon content varies across different habitats and elevation. According to Agren et al. (2013), litter decomposition is region specific and has a strong correlation with OM mineralization. In addition, other factors such as, species richness (SR) also contributes to the accumulation of OM. Available nitrogen (N) exhibited a significantly positive correlation with OC and OM content ($r = 0.8$, $p < 0.05$) (**Figure 3**). It has been reported that humus content is directly proportional to the amount of essential nutrients in soil. OC and phosphorous (P) content were negatively correlated (Gupta and Sharma, 2009). The nitrogen (N) content is dependent on the amount of OM in the soil (Jha et al., 1984). No significant variation was observed in the N content (%) ($F = 1.828$, $p > 0.05$) between the study sites (**Table 2**). N showed a positive correlation with potassium (K) (**Figure 3**). Previous studies carried out by Gupta and Sharma, (Gupta and Sharma, 2009); Mishra et al. (2017) also reported a positive correlation between N and K, which in turn are directly related to OM.

The P content varied significantly ($F = 3.556$, $p < 0.05$) ranging from 43.25 kg/ha^{-1} (SIX) to 77.88 kg/ha^{-1} (SVIII) across the study sites. Highest K content was recorded at SV (619.36 kg ha^{-1}) while SVIII had the lowest content (77.88 kg ha^{-1}). The potassium content in soil is proportional to the parent rock compositions. As the degree of weathering is regulated by altitude and accompanying climatic conditions, variations in K content may be related to habitat features and

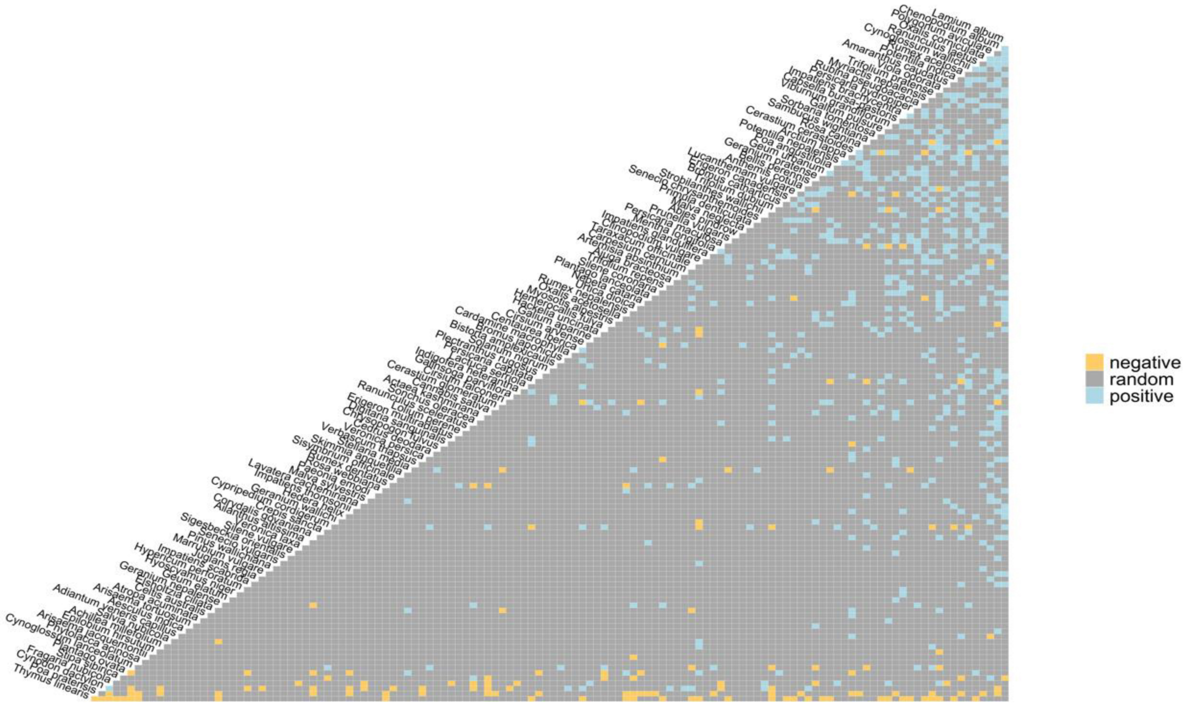

FIGURE 4
Heat map (co-occurrence plot) portraying the significant random negative and positive species relationships.

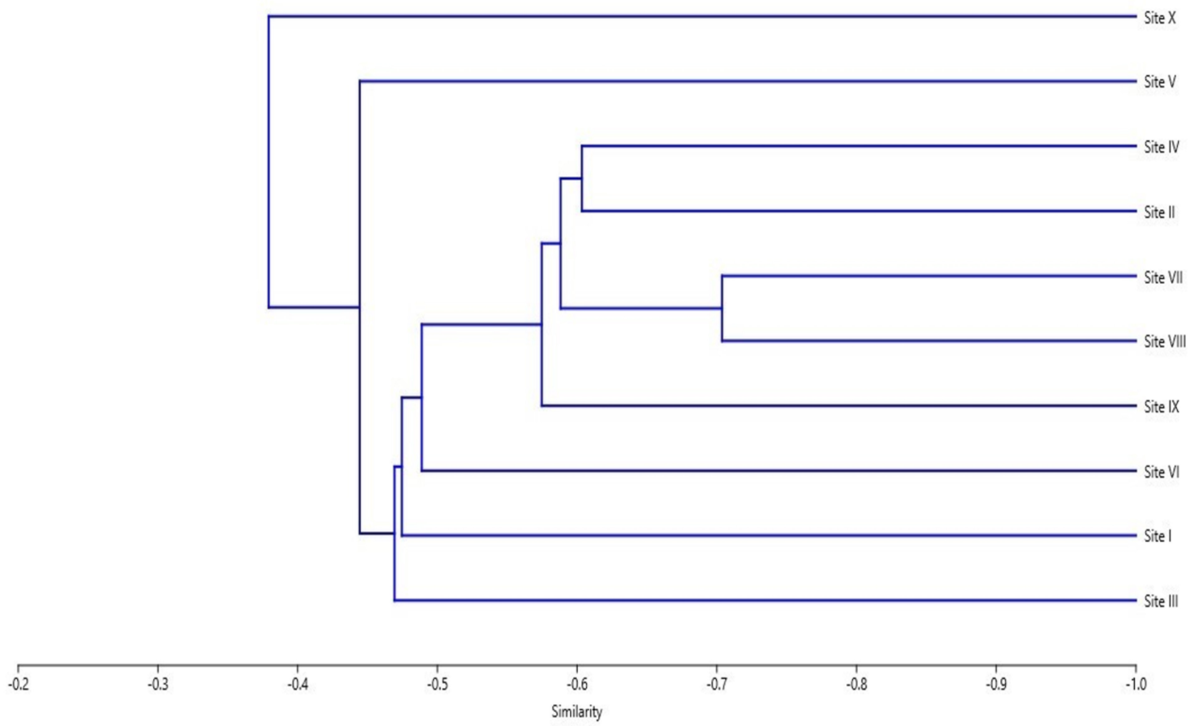

FIGURE 5
Bray-Curtis (Similarity) index among selected sites of the study area.

altitude (Mishra et al., 2017). Further, OC shows a positive correlation with K ($r = 0.15$) and N ($r = 0.8$), but this correlation was significant between OC and N ($p < 0.05$) (**Figure 3**). Owing to the fact that availability of K is maintained through decomposition of organic matter (Basumatary and Bordoloi, 1992), therefore a positive correlation is present between organic carbon and macronutrients (nitrogen and potassium) as both are dependent on the humus content in soil (Mishra et al., 2017).

A sturdy relationship was found between floristic diversity associated with *P. acinosa* and soil parameters across different sites in Kashmir Himalaya. Our results corroborate previous investigations of edaphic factors (Figueiredo et al., 2018; Jucker et al., 2018; Hofhansl et al., 2020), which found that vegetation attributes changed in relation to the regional variation of soil physico-chemical properties across different areas. Plant species composition and distribution is influenced by the soil characteristics (Yang et al., 2018). Across different sites soil properties such as, Ph, OC, OM among others show significant differences, that eventually impact the plant species composition (Rahman et al., 2022). The community composition and species distribution pattern is also regulated by the soil organic matter. Water holding capacity and colloidal nature of soil subsequently increased in plant communities with increase in OM content (Mumshad et al., 2021; Wani I. A. et al., 2022). Higher values of phytosociological parameters across the study sites can be attributed to the favorable soil chemical properties.

The highest degree of similarity (71.39%) was recorded between SVII and SVIII (**Figure 5**), as both sites had almost similar soil characteristics and relatively similar altitudes. SI (fertile forest soil) and SIII (rocky soil) exhibited least similarity (37.01%) which can be ascribed to the variation in habitat characteristics, altitude and soil properties between the two sites, the vegetation composition changed in relation to the regional variation of soil properties and elevation across different areas (Ismail and ELawad, 2015). The presence of entirely random association with other plants (**Figure 4**) revealed that *P. acinosa* inhabit distinct habitats and co-associates in a natural community within a specific geographical area (Gulzar et al., 2022).

Our study has revealed that the change in soil properties leads to subsequent changes in plant communities, especially in terms of species diversity, richness and cooccurrence patterns. Since the plant species respond individually to changing climatic and soil conditions, plant community composition is thus likely to be modified (Lafleur et al., 2010). Environmental factors like soil moisture, temperature and elevation governs the vegetation patterns and soil physico-chemical properties to a greater extent (Solon et al., 2007; Hamid et al., 2021). This interpretation is supported by differentiation in community composition and structural features such as number of species, co-occurrence patterns, and diversity indices. The species richness varied in relation to the combined pattern of edaphic factors like OC, OM, N, and pH, with the number of species being substantially higher where these soil properties except pH were high, and vice-versa (Solon et al., 2007). The present study also reflected that SVII (Daksum) has highest species richness (83), OC (12.39%) and OM (21.36%) content while SX (Khag) had lowest species richness (27), OC (1.16%) and OM (2.00%). Floristic composition and soil fertility of a particular site is largely affected by the anthropogenic activities. The sites with undisturbed and fertile soils have quite rich species diversity and the sites with poor and disturbed soils support minimum plant diversity. The sites characterized by fertile soils, higher floristic diversity and productivity act as potential areas of carbon sequestration (Mishra et al., 2017). Therefore, proper management of such areas will not only help in mitigating the climate change, but also allow the sustainable provisioning of ecosystem services and conservation of floristic diversity. Besides, the sites with the low soil fertility and species diversity need better management strategies for the restoration and plant species conservation.

Since community composition and distribution of plant species is partly under the control of climatic variables like average precipitation and temperature, the projected global climate change is likely to alter the composition and distribution pattern of vegetation (Chen et al., 2011; Brown and Vellend, 2014). Moreover, as soil processes and properties are partially governed by climatic variables, the climate change is also likely to modify soil properties (Gelybo et al., 2018). Floristic composition is influenced by soil physicochemical properties, and any modification in soil factors due to the changing climate leads to the variation in vegetation responses (Lafleur et al., 2010). Hence, relationship between climate, vegetation and soil properties are complex, multi-scale, and multi-aspect in nature. The study of plant-soil systems has become important in understanding plant community composition, population dynamics, and ecosystems functioning. Soil microclimate and other environmental factors that contribute to plant–soil system effect ecosystem composition, species diversity and possibly play a role in the evolution of species (van der Putten et al., 2016). Therefore, a better understanding of ecological and evolutionary repercussions of soil-vegetation interactions might assist in projecting and mitigating the effects of human-induced global climate change, and land use change for the better sustainable future.

Conclusion

The present study indicates that *Phytolacca acinosa* displays a broad range of habitats reflecting its diverse phytosociological amplitude and tolerance to existing environmental conditions. The phytosociological characteristics reveals that in *P. acinosa* communities; *Poa angustifolia, P. pratensis, and Cynadon dactylon* were the dominant species. The findings of present study emphasis on the significance of relationship between soil parameters, vegetation characteristics and plant associations for better understanding of communities' functioning. The lower IVI values of *P. acinosa* than associated plant species divulge its lesser ecological importance and perpetuation in the assemblages, hence needs conservation strategies. Moreover, the soil paraments plays a vital role in the establishment of plant communities with response to environmental conditions. The good soil properties and phytosociological attributes at some sites reflects the relatively stable nature of these sites and vice versa. All these parameters must be taken into consideration while studying species distribution pattern, community characteristics and association in a particular region. From our study it can be concluded that the knowledge of both species diversity and soil properties in different ecosystems can improve conservation efforts and ensure better management strategies for the restoration of degraded habitats over a period of time. In future, similar studies will help in understanding the community ecology their conservation strategies and restoration efforts, to ensure prolonged supply of ecosystem functioning and processes.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

JM: methodology, data collection, and writing - original draft. BW: data collection. TI: curation and analysis, software, and visualization. AG: conceptualization and supervision, methodology, validation, and writing - original draft. IN: conceptualization, supervision, investigation, validation, and writing - review. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2022.976902/full#supplementary-material

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