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Morphological characterization of wild *Rosa* L. germplasm from the Western Himalaya, India

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Abstract The aim of this study was to assess morphological variation in wild *Rosa* L. germplasm from the Western Himalayan Region that includes the geographical area of two Union territories (Jammu and Kashmir [J&K] and Ladakh) and one state (Himachal Pradesh [HP]) of India. Field trips in different locations of J&K, Ladakh, and HP from 2014 to 2018 were undertaken in different seasons to collect accessions of wild *Rosa* species. A total of 59 accessions belonging to six wild *Rosa* species (*Rosa canina* L., *R. foetida* var. *persiana* [Lem.] Rehder, *R. macrophylla* Lindl., *R. moschata* Herrm., *R. multiflora* Thunb. and *R. webbiana* Wall ex. Royle) were collected. Fifty-five vegetative and reproductive characters (39 qualitative and 16 quantitative characters) were recorded for all of the accessions to determine the most significant morphological differences among the six species and among accessions of the same species. Phenotypic variability among the studied accessions was evaluated using descriptive statistics, principal component analysis (PCA), and cluster analysis. Among the quantitative characters analyzed, the coefficient of variation (CV) was highest for the number of rose hips per inflorescence and lowest for petal length; for the qualitative characters, the CV was highest for rose hip shape and lowest for sepal prickles. Results of the PCA indicated that the first six components accounted for 65.44% of the total variation. Leaflet length displayed a significant positive correlation with leaflet width, petiole length and pedicel length. Petal length, petal breadth, and flower diameter were positively correlated with each other. Hip length showed a positive correlation with hip width and a negative correlation with pedicel length, and hip color. Hip number per inflorescence showed a positive correlation with leaflet length, leaflet breadth, petiole length, pedicel length, and a strong negative correlation with prickle length. Clustering analysis categorized the *Rosa* accessions into two clusters and several groups and subgroups, indicating a high level of morphological variation in the germplasm. The key traits among the species identified to have a high discriminating value were leaflet length, leaflet breadth, prickle shape and size, stipule margin, style nature, sepal margin, flower color, and size and shape of hips. These results indicate that there is a high potential for obtaining desirable trait combinations

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Keywords Germplasm characterization · Genetic resource · Wild roses · Principal component analysis · Cluster analysis · Western Himalaya

Introduction

The genus *Rosa* L. belongs to the family Rosaceae and comprises about 200 species (Wissemann 2003) distributed throughout the temperate and sub-tropical habitats of the northern hemisphere (Gu and Robertson 2003). The majority of wild rose species are found in Asia, which is one of the major gene centers of these species (Broertjes and van Harten 1978). Various species of *Rosa* have adapted to the conditions found between 500 and 4700 m a.s.l. in the Indian Himalayan Region (Hooker 1879; Duthie 1971; Bamber 1976; Ambasta 1986; Pal 1991; Tejaswini and Prakash 2005). During the adaption process, these species are likely to have evolved into distinct taxa with the potential to develop into varieties and potential strains that can play a key role in the development of future roses.

A noteworthy feature of rose diversity is the availability of variation in almost all visible morphological characters. This wealth of indigenous germplasm is an important source of many important commercially valued traits, such as perpetual flowering, winter hardiness, fragrance, color, thornlessness, among others. The extremely large phenotypic versatility in subgenus *Rosa* L. has often represented a challenge to botanists, and many species of *Rosa* are remarkably polymorphic and possess different geographical races and ecotypes that are not yet understood. Indeed, species delimitation is so difficult in this subgenus that can become almost impossible to differentiate even between different morphotypes of the same species and the hybrids. This awkward identification of hybrids is caused by the mixed presence of parental, intermediate, transgressive, and newly developed characteristics (Rieseberg and Ellstrand 1993; Werlemark and Nybom 2001). The enormous phenotypic, genotypic, and ecological variability and plasticity in this genus may be due to one or more evolutionary processes, such as hybridization and introgression or others (De Cock 2008).

Roses have been popularized and habitualized throughout the world for their important medicinal and ornamental value (Hummer and Janick 2009). It is one of the more important ornamental plants due to it being a garden plant, a cut flower and a source of essential oil. During recent years, wild roses have become a major focus of research, not only in genetic studies but in other fields. Rose hips, the pseudo-fruits of the rose plant, are utilized in food products in many European countries (Gao et al. 2005) as well as for medicinal purposes (Warholm et al. 2003; Rein et al. 2004; Boskabady et al. 2006). Various phytochemicals reported in rose hips have medicinal properties, including vitamin C (Demir and Ozcan 2001; Roman et al. 2013), quercetin and ellagic acid (Tumbaset et al. 2011), β-carotene and lycopene (Hodisanet et al. 1997). Recently, anti-inflammatory and chondroprotective (Schwager et al. 2014; Marstrand and Campbell-Tofte 2016), anti-ulcerogenic (Gurbuz et al. 2003), anti-oxidant (Gao et al. 2005; Roman et al. 2013), anti-arthritic (Winther 2014; Marstrand and Campbell-Tofte 2016), anti-mutagenic (Karakaya and Kavas 1999) and anti-obese (Nagatomo et al. 2015) properties have also been demonstrated in extracts from various *Rosa* L. species. Wild roses are important source of valuable germplasm for creating variability in and improving cultivated roses, with the potential to satisfy future needs (Dhyani and Singh 2014).

The aim of this study was to assess morphological variation in wild *Rosa* L. germplasm from the Western Himalayan Region that includes the geographical area of two Union territories (Jammu and Kashmir [J&K] and Ladakh) and one state (Himachal Pradesh [HP]) of India. Evaluation of important morphological characters was also conducted to identify wild *Rosa* accessions with good potential for use in rose breeding programs.

Materials and methods

The study area comprised the Western Himalayan Region and included the two Indian Union territories of J&K and Ladakh and the Indian state of HP. The region shares a boundary with China to the east and Pakistan to the west (Fig. 1) and has a total surface area of 3,31,392 km^2 ranging between latitudes 28°

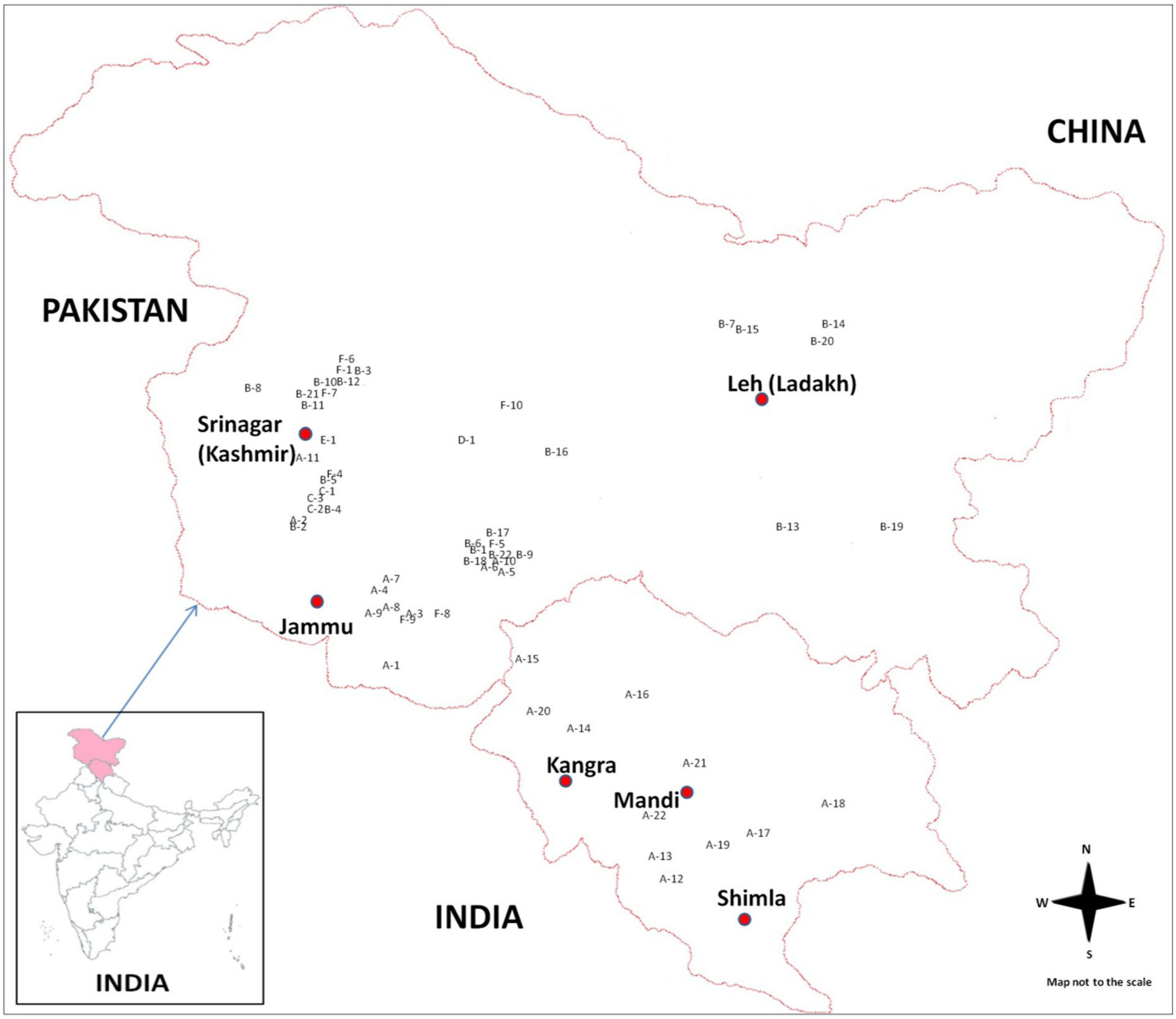


Fig. 1 Map of the study area showing the locations of the collected accessions

43′ and 37° 05′ N and longitudes 72° 31′ and 81° 02′ E. Owing to its multiplicity of habitats, wide range in altitude, conglomerate topography and unique geographic location, this region is home to a rich diversity of plants.

During the study period, field visits were carried out in different parts of the study area in different seasons between 2014 and 2018 to collect accessions of wild *Rosa* species. Ultimately, a total of 59 accessions belonging to six wild *Rosa* species were collected from the different parts of the study area (Table 1; Fig. 2). To identify the specimens, we consulted various monographs (Andrews 1805; Lewis 1957, 1958; Baker 1869), regional Floras (Singh and Kachroo 1976; Kachroo et al. 1977; Sharma and Kachroo 1981; Chowdhery and Wadhwa 1984), electronic Floras (eFloras 2019), eFlora of India (eFI 2018) and regional herbaria (Janaki Ammal Herbarium [RRLH] of CSIR–Indian Institute of Integrative Medicine [IIIM], Jammu, J&K, India; Herbarium of University of Jammu, J&K). Duly identified specimens were submitted to the internationally recognized RRLH at CSIR–IIIM.

In total, we examined 55 morphological characters (39 qualitative and 16 quantitative traits) in all specimens, both in their natural state and in the laboratory (Tables 2, 3). For each of the six wild species of *Rosa* identified, a due effort was made to collect as many accessions as possible. Most traits selected for measurement in this study were chosen based on traits documented in previous studies on rose (Khatamsaz

Table 1 Details of the studied wild *Rosa* accessions collected from the Western Himalaya Region, India

Accession code	Species	Division, district, state	Locality	Latitude	Longitude	Altitude (m.a.s.l.)	RRLH herbarium no.
A-1	*Rosa moschata* Herrm.	Jammu, Kathua, J&K	Pallan	N 32°33.14′	E 075°34.14′	792	23531
A-2	*Rosa moschata* Herrm.	Kashmir, Anantnag, J&K	Bijbehara	N 33°53.46′	E 075°10.16′	2119	23534
A-3	*Rosa moschata* Herrm.	Jammu, Doda, J&K	Bhaderwah	N 32°55.99′	E 075°42.93′	1984	23691
A-4	*Rosa moschata* Herrm.	Jammu, Doda, J&K	Assar	N 33°07.55′	E 075°24.47′	1042	23710
A-5	*Rosa moschata* Herrm.	Jammu, Kishtwar, J&K	Sohal	N 33°13.91′	E 076°12.01′	1979	23546
A-6	*Rosa moschata* Herrm.	Jammu, Kishtwar, J&K	Atholi	N 33°16.10′	E 076°10.25′	1837	23530
A-7	*Rosa moschata* Herrm.	Jammu, Ramban, J&K	Sanasar	N 33°05.97′	E 075°17.54′	2252	23679
A-8	*Rosa moschata* Herrm.	Jammu, Doda, J&K	Doda	N 33°11.33′	E 075°28.43′	1412	23663
A-9	*Rosa moschata* Herrm.	Jammu, Ramban, J&K	Batote	N 33°06.87′	E 075°18.87′	1769	23666
A-10	*Rosa moschata* Herrm.	Jammu, Kishtwar, J&K	Tatapani	N 33°15.80′	E 076°07.71′	1955	23682
A-11	*Rosa moschata* Herrm.	Kashmir, Srinagar, J&K	Solina	N 34°03.40′	E 075°48.00′	1588	23674
A-12	*Rosa moschata* Herrm.	Shimla, Solan, HP	Nihari	N 31°04.90′	E 076°49.63′	815	23647
A-13	*Rosa moschata* Herrm.	Shimla, Bilaspur, HP	Jalapa	N 31°14.73′	E 076°52.10′	1302	23669
A-14	*Rosa moschata* Herrm.	Kangra, Kangra, HP	Bandhiara	N 32°45.65′	E 076°34.12′	1238	23661
A-15	*Rosa moschata* Herrm.	Kangra, Chamba, HP	Dradda	N 32°55.72′	E 076°02.05′	1224	23658
A-16	*Rosa moschata* Herrm.	Kangra, Kullu, HP	Manali	N 32°13.90′	E 077°11.19′	1890	23684
A-17	*Rosa moschata* Herrm.	Shimla, Shimla, HP	Badhal	N 31°32.14′	E 077°49.41′	2380	23685
A-18	*Rosa moschata* Herrm.	Shimla, Kinnaur, HP	Rekong	N 31°33.22′	E 078°16.75′	2013	23529
A-19	*Rosa moschata* Herrm.	Shimla, Shimla, HP	Banuti	N 31°07.68′	E 077°05.87′	1855	23689
A-20	*Rosa moschata* Herrm.	Kangra, Kangra, HP	McLeod Ganj	N 32°14.47′	E 076°56.52′	1745	23693
A-21	*Rosa moschata* Herrm.	Mandi, Mandi, HP	Pali	N 31°49.20′	E 076°56.52′	1218	23687
A-22	*Rosa moschata* Herrm.	Mandi, Mandi, HP	Dahnun	N 31°31.04′	E 076°51.39′	1044	23644

Table 1 continued

Accession code	Species	Division, district, state	Locality	Latitude	Longitude	Altitude (m.a.s.l.)	RRLH herbarium no.
B-1	*Rosa webbiana* Wall. ex Royle	Jammu, Kishtwar, J&K	Ligri	N 33°18.03′	E 075°01.44′	2775	23554
B-2	*Rosa webbiana* Wall. ex Royle	Kashmir, Anantnag, J&K	Khiram	N 33°53.46′	E 075°10.16′	2119	23562
B-3	*Rosa webbiana* Wall. ex Royle	Kashmir, Bandipora, J&K	Gurez	N 33°52.99′	E 075°10.04′	2028	23507
B-4	*Rosa webbiana* Wall. ex Royle	Kashmir, Anantnag, J&K	Langanbal	N 33°58.29′	E 075°18.38′	2332	23589
B-5	*Rosa webbiana* Wall. ex Royle	Kashmir, Anantnag, J&K	Betaab Valley	N 34°03.34′	E 075°21.64′	2440	23549
B-6	*Rosa webbiana* Wall. ex Royle	Jammu, Kishtwar, J&K	Wassar	N 33°19.60′	E 075°45.77′	1605	23510
B-7	*Rosa webbiana* Wall. ex Royle	Leh, Ladakh	Trichit	N 33°42.51′	E 077°57.08′	3572	23544
B-8	*Rosa webbiana* Wall. ex Royle	Kashmir, Kupwara, J&K	Goose	N 34°31.78′	E 074°17.67′	2025	23606
B-9	*Rosa webbiana* Wall. ex Royle	Jammu, Kishtwar, J&K	Sohal	N 33°13.23′	E 076°12.19′	2094	23558
B-10	*Rosa webbiana* Wall. ex Royle	Kashmir, Bandipora, J&K	Bandipora Gurez road	N 34°28.95′	E 074°57.30′	2378	23565
B-11	*Rosa webbiana* Wall. ex Royle	Kashmir, Bandipora, J&K	Bandipora Gurez road	N 34°28.34′	E 074°37.84′	2195	23514
B-12	*Rosa webbiana* Wall. ex Royle	Kashmir, Bandipora, J&K	Dawar	N 33°52.99′	E 075°10.04′	2028	23504
B-13	*Rosa webbiana* Wall. ex Royle	Kargil, Ladakh	Chutak	N 34°26.27′	E 076°03.55′	2803	23597
B-14	*Rosa webbiana* Wall. ex Royle	Leh, Ladakh	South Pullu	N 34°14.49′	E 077°36.89′	4504	23539
B-15	*Rosa webbiana* Wall. ex Royle	Leh, Ladakh	Diskit	N 34°21.37′	E 077°38.31′	3218	23538
B-16	*Rosa webbiana* Wall. ex Royle	Kargil, Ladakh	BudhKharbu	N 34°20.66′	E 076°33.38′	3494	23542
B-17	*Rosa webbiana* Wall. ex Royle	Jammu, Kishtwar, J&K	Machail	N 33°25.09′	E 076°20.82′	2783	23574
B-18	*Rosa webbiana* Wall. ex Royle	Jammu, Kishtwar, J&K	Kundal	N 33°15.26′	E 076°09.17′	2021	23583

Table 1 continued

Accession code	Species	Division, district, state	Locality	Latitude	Longitude	Altitude (m.a.s.l.)	RRLH herbarium no.
B-19	*Rosa webbiana* Wall. ex Royle	Leh, Ladakh	Nyoma	N 33°16.14′	E 078°28.17′	4143	23537
B-20	*Rosa webbiana* Wall. ex Royle	Leh, Ladakh	Khardung La	N 34°24.39′	E 077°39.25′	4024	23543
B-21	*Rosa webbiana* Wall. ex Royle	Kashmir, Bandipora, J&K	Tragbal	N 34°30.15′	E 074°38.30′	3051	23605
B-22	*Rosa webbiana* Wall. ex Royle	Jammu, Kishtwar, J&K	Atholi	N 33°16.10′	E 076°16.10′	1844	23580
C-2	*Rosa canina* L.	Kashmir, Anantnag, J&K	Langanbal	N 33°57.48′	E 075°18.04′	2009	23501
C-3	*Rosa canina* L.	Kashmir, Anantnag, J&K	Lidder Park	N 34°01.23′	E 075°19.03′	2146	23611
D-1	*Rosa foetida* var. *persiana* (Lem.) Rehder	Kargil, Ladakh	Sankoo	N 34°17.68′	E 075°57.28′	3007	23602
E-1	*Rosa multiflora* Thunb.	Kashmir, Srinagar, J&K	Foreshow	N 34°08.73′	E 074°51.45′	1543	23614
F-1	*Rosa macrophylla* Lindl.	Kashmir, Bandipora, J&K	Chorwan	N 34°34.48′	E 074°39.05′	2848	23704
F-2	*Rosa macrophylla* Lindl.	Mandi, Chamba, HP	Khajjar	N 32°32.17′	E 076°02.43′	2169	23619
F-3	*Rosa macrophylla* Lindl.	Mandi, Kullu, HP	Rohtang	N 32°19.21′	E 077°13.31′	3256	23517
F-4	*Rosa macrophylla* Lindl.	Kashmir, Anantnag, J&K	Frislan	N 34°03.67′	E 075°21.94′	2488	23521
F-5	*Rosa macrophylla* Lindl.	Jammu, Kishtwar, J&K	Machail	N 33°35.68′	E 074°38.32′	2938	23628
F-6	*Rosa macrophylla* Lindl.	Kashmir, Bandipora, J&K	Chorwan	N 34°34.48′	E 074°39.05′	2848	23618
F-7	*Rosa macrophylla* Lindl.	Kashmir, Bandipora, J&K	Kanzalwan	N 34°39.04′	E 074°43.11′	2552	23594
F-8	*Rosa macrophylla* Lindl.	Jammu, Doda, J&K	Seoj	N 32°53.26′	E 075°39.41′	3460	23640
F-9	*Rosa macrophylla* Lindl.	Jammu, Doda, J&K	Chattergala	N 32°52.48′	E 075°43.68′	3176	23642
F-10	*Rosa macrophylla* Lindl.	Kargil, Ladakh	Karit	N 34°30.98′	E 076°29.67′	3173	23616

HP, Indian state of Himachal Pradesh; J&K, Indian Union territory of Jammu and Kashmir; RRLH, Janaki Ammal Herbarium

Fig. 2 Morphological variation in habit and flower color of wild *Rosa* accessions from the Western Himalaya Region, India. **a**, **b** *Rosa moschata* Herrm., **c**–**h** *Rosa webbiana* Wall. ex Royle, **i**–**r** *Rosa macrophylla* Lindl., **s**, **t** *Rosa canina* L., **u**, **v** *Rosa foetida* var *persiana* (Lem.) Rehder, **w**, **x** *Rosa multiflora* Thunb

1992; Olsson et al. 2000; Werlemark and Nybom 2001; Koobaz et al. 2009; Cheikh-Affeneet et al. 2015), with modifications. Rose descriptors developed by the National Bureau of Plant Genetic Resources (NBPGR; Regional Station, Phagli, Shimla, HP, India; Rathore and Srivastava 1992) were used with modification for

Table 2 Coding key for the 39 morphological characters (qualitative and quantitative traits) studied in the collected wild *Rosa* accessions from the Western Himalaya Region, India

Serial no.	Trait	Coding key for the character
1	Prickle shape	(1) Curved; (2) straight; (3) subulate; (4) straight to subulate; (5) hooked
2	No. of leaflets	(1) 3–7; (2) 5–9; (3) 5–11; (4) 3–9; (5) 7–9; (6) 3–13; (7) 7–11; (8) 3–11
3	Hair on abaxial leaflet surface	(1) Few hairs; (2) glabrous; (3) hairy
4	Hair on adaxial leaflet surface	(1) Few hairs; (2) glabrous
5	Glands on abaxial leaf surface	(1) Eglandular; (2) glandular
6	Leaflet margin	(1) Singly serrated; (2) singly and doubly serrated
7	Glands on leaflet margin	(1) Glandular; (2) eglandular
8	Leaflet shape	(1) Ovate to lanceolate; (2) orbicular; (3) orbicular to obovate; (4) obovate to elliptic; (5) ovate to elliptic; (6) ovate and obovate; (7) ovate
9	Leaflet apex	(1) Acute; (2) acuminate; (3) acute and acuminate; (4) obtuse and truncate; (5) acute, obtuse and truncate; (6) acute and obtuse
10	Leaflet base	(1) Obtuse; (2) cuneate; (3) obtuse and cuneate; (4) obtuse and slightly cuneate
11	Prickles on rachis	(1) Prickly; (2) glabrous; (3) prickly and glabrous
12	Glands on rachis	(1) Glandular; (2)eglandular
13	Stipule shape	(1) Winged; (2) winged and fringed
14	Stipule apex	(1) Acute; (2) acuminate; (3) acute and flat in few; (4) acute and obtuse
15	Hairs on stipules	(1) Hairy; (2) glabrous
16	Glands on stipules	(1) Glandular; (2) eglandular; (3) glandular and eglandular
17	Hair onhypanthium	(1) Hairy; (2) glabrous; (3) none of these
18	Glands on hypanthium	(1) Glandular; (2) eglandular; (3) glandular and eglandular in few; (4) none of these
19	Hair on pedicel	(1) Hairy; (2) glabrous
20	Glands on pedicel	(1) Glandular; (2) eglandular; (3) glandular and eglandular
21	Number of bracts	(1) Zero; (2) one; (3) two
22	Shape of bract	(1) Boat with turning to leaf like on one end and large in size; (2) boat with turning to leaf like on one end and small in size; (3) lanceolate to triangular; (4) obovate (5) none of these
23	Sepal form	(1) Erect; (2) reflexed; (3) erect and reflexed
24	Edge of sepal	(1) Entire; (2) multiple large sized lobes; (3) deeply pinnatified; (4) few small sized lobes; (5) two pinnae only
25	Sepal permanancy	(1) Deciduous; (2) non deciduous
26	Sepal apex	(1) Narrow; (2) spatulate; (3) narrow to spatulate
27	Glands on sepals	(1) Glandular; (2) eglandular
28	Prickle on sepals	(1) Present; (2) absent
29	Petal apex	(1) Emarginate and mucronate; (2) emarginate,rounded to truncate; (3) emarginate, rounded and incised; (4) emarginate; (5) obtuse, mucronate to emarginate
30	Petal color	(1) Pink; (2) white; (3) yellow; (4) pink and white
31	Flower fragrance	(1) Intense rose; (2) mild rose; (3) other
32	Style nature	(1) Connate and hairy; (2) free and hairy; (3) connate and glabrous
33	Color of filament	(1) White; (2) greenish white; (3) yellow; (4) white to light pink; (5) yellow to white
34	Nature of whorls of stamens	(1) Irregular; (2) cyclic
35	Color of anther	(1) Yellow; (2) brownish yellow; (3) yellowish white and dark brownish

Table 2 continued

Serial no.	Trait	Coding key for the character
36	Hairs on hips	(1) Hairy; (2) glabrous; (3) none of these
37	Glands on hips	(1) Eglandular; (2) glandular; (3) eglandular or glandular; (4) none of these
38	Color of hips	(1) Red; (2) reddish orange; (3) orange; (4) none of these
39	Shape of hips	(1) Ovoid to subglobose; (2) globose; (3) pyriform; (4) ovoid to globose; (5) subglobose to pyriform; (6) oblong-ovoid; (7) urceolate to ovoid; (8) oblong, ovoid to pyriform; (9) ovoid to pyriform; (10) subglobose; (11) obovate; (12) none of these

assigning descriptor nodes for the documentation of morphological traits. For the morphological studies, we randomly selected four plants from each accession for study. The methodology of De Cock (2008) was followed for leaflet measurements. Flower traits were analyzed at the flowering stage. Hips (fruits) were collected for measurements at the ripened stage. All measurements were made with a Vernier caliper with an accuracy of 0.1 mm.

Statistical analysis

Data were analyzed for variance, and comparison of means were performed with Tukey's post hoc test using Minitab 17 (Minitab, LLC, State College, PA, USA). Coefficients of variation (CV) were determined as indicators of variability. A correlation analysis was ascertained using the Pearson correlation coefficient for the assessment of relationships between some economically important morphological traits (both quantitative and qualitative) in the studied *Rosa* species. For the grouping of the wild *Rosa* accessions based on similarities in their morphological traits, we performed principal component analysis (PCA) and cluster analysis with the unweighted pair group method with arithmetic mean (UPGMA) using the PAST 3.22 software program (Hammer et al. 2001).

Results

Phenotypic characterization of *Rosa* accessions

A wide range of phenotypic plasticity was observed in the studied morphological characters (both qualitative and quantitative traits) of the wild *Rosa* species collected in this study. The range in the variation found for these floral and vegetative morphological traits (qualitative) in these wild *Rosa* species is presented in Table 3. Among the qualitative traits, maximum variation was observed for hip shape followed by leaflet shape and leaflet number. Prickles were present in various forms, ranging from curved in *R. moschata* and *R. multiflora*, straight in *R. webbiana* and *R. foetida* var. *persiana*, straight to subulate in *R. macrophylla* and hooked in *R. canina*. The distribution pattern of prickles along the stem and branches also showed variation in the studied accessions. All accessions of *R. moschata*, *R. canina*, *R. multiflora,* and *R. foetida* var. *persiana* displayed the moderately dense distribution of prickles, while accessions of *R. webbiana* and *R. macrophylla* showed a mixed-type distribution pattern. This overall range in the distribution pattern of prickles and their different forms are in accordance with the results of studies carried out by Debener and Linde (2009). One prickleless accession (F-4) of *R. macrophylla* was found during the field study, which is in consonance with results documented in the literature. As prickles are considered to be an undesirable trait in commercial rose cultivation, particularly in terms of cultivation and harvesting, the search for thornless cultivars has been a key breeding objective of almost all rose breeding programs (Zlesak 2007; Kanli and Kazaz 2009). Large-sized sticky glandular hairs were found on the hip surface of *R. macrophylla* accession F-1 and F-6; these may be an adaptation against herbivory.

One new observation recorded was the presence of fine needle-shaped prickles on the sepal surface of accession F-6, which was collected from the Gurez Valley, Kashmir. Some leaflets of accessions F-1 and F-8 have a glandular abaxial surface, which is one of the characters of *R. macrophylla* var. *glandulifera*,

Table 3 Range of variability in the morphological characters of the collected wild *Rosa* species

Serial no.	Morphological characters	Abbreviations of morphological characters	Unit[a]	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation (%)
Quantitative characters								
1	Leaflet length	LfL	Millimeter	4	55	26.93	13.45	49.94
2	Leaflet breadth	LfB	Millimeter	4	26	13.83	4.93	35.65
3	Petiole length	PtL	Millimeter	4	35	17.44	6.52	37.39
4	Stipule length	StL	Millimeter	3	26	10.28	3.96	38.52
5	Stipule breadth	StB	Millimeter	1	9	3.24	1.64	50.62
6	Pedicel length	PdL	Millimeter	6	55.5	21.33	8.91	41.79
7	Sepal length	SL	Millimeter	6	32	16.85	4.92	29.20
8	Sepal breadth	SB	Millimeter	1	8	3.39	0.98	28.91
9	Petal length	PL	Millimeter	16	29	22.94	2.3	10.03
10	Petal breadth	PB	Millimeter	13	28	21.04	2.41	11.45
11	Flower diameter	FlD	Millimeter	34	63	46.27	4.8	10.37
12	Hip length	HL	Millimeter	5	32	14.11	5.23	37.07
13	Hip width	HW	Millimeter	4	18	9.75	1.96	20.10
14	Achene number	AN	Number	1	43	18.83	5.7	30.27
15	Prickle length	PrL	Millimeter	0	17	6.95	3.49	50.22
16	Hip number/ inflorescence	HNI	Number	0	28	5.70	5.50	96.83
Qualitative characters								
17	Prickle shape	PrS	Code	1	5	–		–
18	No. of leaflets	LfN	Code	1	8	–		–
19	Hair on abaxial leaflet surface	LfHab	Code	1	3	–		–
20	Hair on adaxial leaflet surface	LfHad	Code	1	2	–		–
21	Glands on abaxial leaflet surface	LfGab	Code	1	2	–		–
22	Leaflet margin	LfM	Code	1	2	–		–
23	Glands on leaflet margin	LfMG	Code	1	2	–		–
24	Leaflet shape	LfS	Code	1	7	–		–
25	Leaflet apex	LfAp	Code	1	6	–		–
26	Leaflet base	LfBa	Code	1	4	–		–
27	Glands on rachis	RG	Code	1	2	–		–
28	Prickles on rachis	RPr	Code	1	3	–		–
29	Stipule shape	StS	Code	1	2	–		–
30	Stipule apex	StA	Code	1	4	–		–
31	Hairs on stipules	StH	Code	1	2	–		–
32	Glands on stipules	StG	Code	1	3	–		–
33	Hair on hypanthium	HypH	Code	1	3	–		–
34	Glands on hypanthium	HyG	Code	1	4	–		–
35	Hair on pedicel	PdH	Code	1	2	–		–
36	Glands on pedicel	PdG	Code	1	3	–		–

Table 3 continued

Serial no.	Morphological characters	Abbreviations of morphological characters	Unit[a]	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation (%)
37	Number of bract	BrN	Code	1	3	–		–
38	Shape of bracts	BrS	Code	1	4	–		–
39	Sepal form	SpF	Code	1	3	–		–
40	Edge of sepal	SpE	Code	1	5	–		–
41	Sepal permanency	SpPr	Code	1	2	–		–
42	Sepal apex	SpA	Code	1	3	–		–
43	Glands on sepals	SpG	Code	1	2	–		–
44	Prickle on sepals	SpPr	Code	1	2	–		–
45	Petal apex	PA	Code	1	5	–		–
46	Petal color	PC	Code	1	4	–		–
47	Flower fragrance	FlF	Code	1	3	–		–
48	Style nature	Sty	Code	1	2	–		–
49	Color of filament	FlC	Code	1	5	–		–
50	Nature of whorls of stamens	WhS	Code	1	2	–		–
51	Color of anther	AnC	Code	1	3	–		–
52	Hairs on hips	HH	Code	1	3	–		–
53	Glands on hips	HG	Code	1	4	–		–
54	Color of hips	HC	Code	1	4	–		–
55	Shape of hips	HS	Code	1	12	–		–

[a]See Table 1 for codes

suggesting that different *Rosa* species intermediates may occur naturally, possibly as the result of frequent and unrestricted crossing in wild *Rosa*. Wild *Rosa* species harbor different alleles that can be incorporated by introgression into various other species of *Rosa* as well as into other important crop plants for generating variability. Of all the species of *Rosa* studied here, the petals of *R. moschata* possess the strongest scent, thereby suggesting its potential use in the aroma industry. However, further studies are required to actually prove the economic potential of the oil of these *Rosa* species.

Prickle shape, leaflet shape, stipule and sepal attributes, filament color, nature of style, and shape of hips were found to be major discriminating qualitative traits in some of the studied species in terms of species delimitation. However, the contribution of other qualitative characters in affecting either species delimitation or accession discrimination cannot be ignored, as observed in our study.

The descriptive statistical results for each of the 16 quantitative characters studied are shown in Table 3. For the quantitative traits, as indicated by the value of the CV (Table 3), the lowest variation was documented for petal length (10.03%), and the highest was documented for hip number/inflorescence (96.83%). The results of the comparison of means of the studied quantitative characters using Tukey's post hoc test is shown in Table 4. Mean values of quantitative traits with the standard error of each accession growing wild in the Western Himalayan Region are given in Electronic Supplementary Material (ESM) Table 2. The highest mean values for leaflet length and leaflet breadth were recorded for *R. moschata* accessions A-4, and A-5, and the lowest (minimum) values were recorded for accession *R. webbiana* accession B-1 (Table 4). In terms of petal and flower dimensions, the highest mean values for petal length and petal breadth were determined for *R. webbiana* accession B-2, and the lowest values were found for *R. webbiana* accession B-17 and *R. moschata* accession A-5

Table 4 Mean values of quantitative morphological characters of wild *Rosa* accessions collected from the Western Himalaya Region, India

Accession no.	Quantitative morphological characters of wild *Rosa* accessions							
	LfL (mm)	LfB (mm)	PtL (mm)	StL (mm)	StB (mm)	SL (mm)	SB (mm)	PL (mm)
A-1	41.65 efghi	17.63 hijk	28.60 b	11.25 klmno	2.13 qrstuvwx	14.40 tuvwxyz	2.70 opqrstuvw	22.20 mnopqrstu
A-2	42.60 defgh	18.28 ghij	31.80 a	13.65 fgh	1.95 tuvwx	21.65 efghi	2.90 mnopqrstu	22.50 klmnopqrs
A-3	41.20 efghi	19.75 cdefg	23.70 cde	12.05 hijklm	2.85 klmnop	16.50 nopqrst	2.43 tuvw	25.95 c
A-4	43.95 cde	19.90 defg	22.55 defg	14.25 efg	3.48 jk	24.00 cde	3.30 ijklmno	22.95 ghijklmno
A-5	43.45 cdefg	22.15 a	29.95 ab	14.30 efg	2.98 klmn	19.20 ijklm	3.13 jklmnopqr	20.80 wx
A-6	40.90 fghi	14.00 mn	17.90 jklm	8.10 rstuvw	2.20 opqrstuvw	17.95 klmnop	3.40 hijklmn	23.40 fghijkl
A-7	42.85 defgh	16.00 kl	23.95 cde	10.45 mnopq	2.33 mnopqrstuv	18.50 jklmno	2.93 lmnopqrstu	23.95 defg
A-8	43.65 cdef	20.15 cdef	24.05 cde	11.70 ijklmn	2.58 lmnopqrst	15.45 pqrstuv	2.83 nopqrtuv	24.75 de
A-9	43.50 cdefg	20.35 bcde	23.90 cde	11.20 lmno	2.83 klmnopq	14.70 stuvwx	2.58 qrstuvw	23.70 efghij
A-10	47.75 ab	21.00 abcd	18.60 ijkl	11.80 hijklm	2.36 mnopqrstuv	20.60 ghij	3.10 jklmnopqrs	23.35f ghijkl
A-11	37.20 jk	15.95 kl	22.60 defg	11.05 lmno	2.20 opqrstuvw	17.80 klmnopq	3.18 jklmnopq	22.35 lmnopqrstu
A-12	45.70 bc	21.70 ab	24.65 cd	10.30 mnopq	2.13 qrstuvwx	13.80 vwxyzAB	2.90 mnopqrstu	23.45 fghijk
A-13	44.75 cd	21.00 abcd	20.75 fghi	12.00 hijklm	2.70 lmnopqrs	12.60 wxyzABCD	3.65 hij	22.40 klmnopqrst
A-14	34.65 kl	12.15 opqr	16.95 lm	9.85 nopqr	2.10 rstuvwx	17.00 mnopqrs	3.50 hijklm	23.45f ghijk
A-15	41.60 efghi	17.45 ijk	22.20 defgh	10.75 lmnop	1.18 y	15.15 rstuvw	2.40 tuvw	22.95 ghijklmno
A-16	41.50 efghi	16.30 kl	23.90 cde	7.15 tuvwxyzA	1.46 xy	15.40 pqrstuv	2.15 w	23.20 fghijklm
A-17	49.95 a	21.40 abc	17.95 jklm	6.95 vwxyzAB	1.50 wxy	16.40 opqrstu	2.80 nopqrstuv	23.80 defgh
A-18	39.80 ij	19.65 defg	19.75 hijk	5.95 xyzABC	1.18 y	17.45 lmnopqr	2.78 nopqrstuvw	22.65 jklmnopqr
A-19	40.80 ghi	15.05 lm	23.55 cde	7.45 tuvwxy	1.80 uvwxy	16.80 mnopqrst	3.63 hij	22.05 nopqrstuv
A-20	40.60 hi	18.55 fghi	25.30 c	11.70 ijklmn	1.70 vwxy	17.65 klmnopqr	2.65 pqrstuvw	23.00 ghijklmn
A-21	32.65 lm	15.00 lm	19.60 hijk	8.80 qrstuv	1.58 wxy	14.30 tuvwxyzA	3.48 hijklm	22.40 klmnopqrst
A-22	48.151 ab	18.40 ghi	17.85 jklm	13.25 fghij	3.05 kl	13.85 uvwxyzAB	2.48 stuvw	23.05 ghijklmn
B-1	8.75 C	7.10 ABC	9.65 vwx	7.15 tuvwxyzA	3.93 ij	11.05 CD	2.70 opqrstuvw	22.33 lmnopqrstu
B-2	9.65 BC	7.70 zABC	10.80 tuvw	7.80 stuvwx	2.95 klmn	12.05 yzABCD	3.40 hijklmn	28.15 a
B-3	12.15 xyzAB	9.25 uvwxyz	11.05 tuvw	9.53 opqrs	2.90 klmno	12.50 xyzABCD	3.24 ijklmnop	24.78 de
B-4	10.15 zABC	8.35 xyzAB	10.65 tuvw	8.65 qrstuv	2.75 lmnopqrs	11.35 BCD	2.30 uvw	27.00 bc
B-5	12.60 wxyz	9.95 tuvwx	11.60 rstuv	9.90 nopqr	3.03 klm	19.75 ijkl	3.73 ghij	19.60 xy
B-6	10.75 zABC	8.25 xyzAB	6.75 z	4.33 C	2.80 klmnopqr	19.60 ijkl	3.53 hijklm	27.80 ab
B-7	12.85 wxyz	9.05 vwxyz	6.80 yz	7.05 uvwxyzAB	4.00 hij	10.75 D	4.00 efgh	21.50 stuvw
B-8	12.30 xyzAB	8.75 wxyzA	8.75 wxyz	5.78 yzABC	2.30 nopqrstuv	12.35 xyzABCD	2.23 vw	21.90 opqrstuv
B-9	10.55 zABC	9.05 vwxyz	9.40 vwxy	7.00 vwxyzAB	3.13 kl	17.30 lmnopqr	3.13 jklmnopqr	23.15 fghijklm

Table 4 continued

Accession no.	Quantitative morphological characters of wild *Rosa* accessions							
	LfL (mm)	LfB (mm)	PtL (mm)	StL (mm)	StB (mm)	SL (mm)	SB (mm)	PL (mm)
B-10	10.20 zABC	7.25 ABC	7.25 xyz	4.30 C	1.85 uvwxy	11.40 BCD	3.15 jklmnopqr	21.30 uvwx
B-11	11.10 yzABC	8.15 yzAB	9.70 vwx	5.60 yzABC	2.78 klmnopqr	11.80 ABCD	3.10 jklmnopqrs	22.80 hijklmnopq
B-12	10.95 yzABC	7.80 zAB	11.25 stuvw	5.80 yzABC	1.95 tuvwx	10.35 D	3.88 fghi	27.45 ab
B-13	14.65 wx	9.75 tuvwxy	14.15 nopqr	7.30 tuvwxyz	2.78 klmnopqr	11.95 zABCD	2.98 klmnopqrst	23.75 efghi
B-14	9.20 C	6.05 C	10.65 tuvw	6.70 wxyzAB	2.33 mnopqrstuv	12.60 wxyzABCD	2.58 qrstuvw	21.75 qrstuvw
B-15	20.75 st	10.98 qrstu	17.25 klm	8.95 pqrst	2.48 lmnopqrstu	14.60 stuvwxy	2.73 opqrstuvw	21.35 tuvwx
B-16	17.55 uv	9.95 tuvwx	12.45 qrstu	6.35 wxyzAB	2.05 stuvwx	19.05 jklmn	3.50 hijklm	23.20 fghijklm
B-17	9.80 ABC	7.70 zABC	9.05 vwxyz	5.25 BC	1.73 vwxy	12.50 xyzABCD	1.48 x	17.85 z
B-18	17.50 uv	11.05 qrst	13.75 pqrs	8.90 pqrstu	2.15 pqrstuvwx	15.30 qrstuv	2.53 rstuvw	22.80 hijklmnopq
B-19	15.20 vw	10.70 rstuv	14.10 pqr	5.50 zABC	2.15 pqrstuvwx	13.45 vwxyzABC	3.55 hijkl	22.75 hijklmnopq
B-20	10.20 zABC	6.80 BC	11.10 tuvw	5.38 ABC	1.83 uvwxy	13.90 uvwxyzAB	2.90 mnopqrstu	21.65 rstuvw
B-21	20.40 wxyzA	13.85 xyzAB	14.40 qrst	9.85 nopqr	5.80 d	25.55 bcd	4.75 bcd	21.05 vwx
B-22	13.65 wxy	9.10 vwxyz	9.90 uvw	9.55 opqrs	4.70 fgh	11.75 ABCD	3.70 hij	20.35wx
C-1	28.50 no	16.9 5ijk	24.20 cde	21.15 a	6.58 bc	22.85 efg	4.35 defg	21.85 pqrstuvw
C-2	30.15 mn	19.35 defgh	22.50 defg	16.10 de	5.83 d	23.35 def	5.05 abc	22.85 hijklmnop
C-3	28.25 no	19.45 defg	19.00 ijkl	18.10 bc	5.30 def	23.40 de	5.55 a	23.95 defg
D-1	25.90 op	13.65 mno	20.30 ghij	11.001 mno	4.35 ghi	14.42 tuvwxyz	5.30 ab	22.18 mnopqrstu
E-1	23.45 pqrs	16.55 jkl	21.85 efgh	19.00 b	4.48 ghi	10.70 D	4.48 cdef	22.80 hijklmnopq
F-1	22.25 rst	11.13 qrst	15.90 mnop	11.60 jklmn	5.48 de	20.15 hijk	3.73 ghij	21.98 nopqrstuv
F-2	35.20 kl	18.65 efghi	23.15 cdef	12.50 ghijkl	4.00 hij	20.80 fghij	3.33 ijklmno	21.05 vwx
F-3	24.00 pqr	11.18 qrst	17.95 jklm	13.50 fghi	5.95 cd	18.40 jklmno	3.58 hijk	19.15 yz
F-4	22.15 rst	11.45 pqrst	14.20 nopqr	16.25 cd	4.58 ghi	27.55 ab	3.53 hijklm	24.20 def
F-5	25.85 op	13.05 nop	16.75 lmn	13.10 fghijk	4.08 hij	26.25 abc	4.65 cd	23.65 fghij
F-6	20.20 tu	10.35 stuvw	14.23 nopq	9.70 opqr	5.00 efg	28.25 a	5.00 abc	27.65 ab
F-7	25.20 pq	16.25 kl	25.25 c	14.55 def	4.83 efg	15.30 qrstuv	4.48 cdef	26.20 c
F-8	23.50 pqrs	11.90 pqrs	14.05 opqr	13.30 fghij	5.50 de	22.55 efgh	4.55 cde	22.70 ijklmnopqr
F-9	22.90 qrst	12.60 nopq	22.80 cdefg	14.40 def	7.20 ab	18.30 jklmno	3.83 ghi	24.85 d
F-10	21.70 rst	14.83 lm	16.60 lmno	15.85 de	7.45 a	19.80 ijkl	4.95 abcd	22.50 klmnopqrs

Accession no.	Quantitative morphological characters of wild *Rosa* accessions							
	PB (mm)	FlD (mm)	PdL (mm)	HL (mm)	HW (mm)	AN (*n*)	PrL (mm)	HNI (*n*)
A-1	20.55 mnopqrs	45.95 klmnopqrs	28.30 ghij	10.80 stuvwxyz	8.63 nopqrstu	11.60 y	3.30 tuvw	10.30 cde

Table 4 continued

Accession no.	Quantitative morphological characters of wild *Rosa* accessions							
	PB (mm)	FlD (mm)	PdL (mm)	HL (mm)	HW (mm)	AN (*n*)	PrL (mm)	HNI (*n*)
A-2	21.05 lmnopqr	45.80 klmnopqrs	33.15 de	10.60 tuvwxyzA	7.85 stu	18.40 lmnopq	3.75 stuvw	10.10 cde
A-3	21.60 jklmn	47.55 efghijk	28.80 ghi	14.50 fghij	8.50 pqrstu	23.4 5defg	3.95 stuvw	16.60 a
A-4	21.15 lmnopqr	48.30 efgh	35.55 cd	13.95 ghijklmn	8.85 mnopqrstu	23.30 defg	3.95 stuvw	11.95 bc
A-5	17.30 y	45.75 klmnopqrs	36.65 c	11.95 nopqrstuvw	8.95 klmnopqrstu	17.90 lmnopqr	4.30 rstuv	11.85 bc
A-6	20.55 mnopqrs	47.90 efghij	27.55 hijk	11.35 qrstuvwxy	8.30 qrstu	16.25 nopqrstuvw	4.05 stuvw	9.10 de
A-7	21.25 lmnopq	44.90 pqrstuv	27.30 hijk	11.85 opqrstuvwx	9.80 hijklmnop	24.00 cdefg	4.50 qrst	11.80 bc
A-8	20.65 mnopqrs	48.95 def	25.20 klmno	10.40 uvwxyzAB	8.35 qrstu	21.80 ghijk	3.40 tuvw	10.80 cde
A-9	19.95 rstuv	45.55 mnopqrst	24.20 mno	9.90 xyzAB	7.85 stu	22.25 fghi	3.80 stuvw	11.15 bcd
A-10	20.45 nopqrs	44.70 qrstuv	32.30 ef	10.90 stuvwxyz	8.85 mnopqrstu	19.15 jklmn	3.50 tuvw	12.25 bc
A-11	19.15 tuvwx	41.80 xy	33.15 de	11.20 qrstuvwxy	8.75 mnopqrstu	18.75 lmnop	3.43 tuvw	13.40 b
A-12	20.70 lmnopqrs	46.90 ghijklmno	28.15 ghij	8.65 AB	8.15 rstu	22.00 ghij	3.48 tuvw	12.30 bc
A-13	20.30 opqrst	45.35 nopqrst	26.00 jklmn	9.50 yzAB	8.90lmnopqrstu	23.10 efg	2.63 w	9.05 de
A-14	21.10 lmnopqr	47.25 fghijklm	22.75 op	11.55 pqrstuvwx	9.90 fghijklmn	16.95 lmnopqrs	2.90 uvw	13.40 b
A-15	20.15 qrstu	45.50 mnopqrst	24.55 lmno	11.05 rstuvwxy	9.15 klmnopqrs	18.40 lmnopq	3.13 tuvw	10.00 cde
A-16	20.50 mnopqrs	46.60 hijklmnop	24.95 klmno	10.00 wxyzAB	8.15 qrstu	13.40 wxy	2.85 vw	11.30 bcd
A-17	21.45 klmno	47.20 fghijklmn	25.70 jklmn	9.85 xyzAB	7.70 u	16.50 nopqrstu	3.00 uvw	10.30 cde
A-18	20.10 qrstu	46.15 ijlmnopq	30.70 efg	10.10 vwxyzAB	8.10 stu	18.90 klmno	2.68 w	17.75 a
A-19	19.00 uvwx	44.60 qrstuv	23.00 nop	10.00 wxyzAB	9.45 jklmnopqr	19.75 hijkl	4.35 rstu	8.75 e
A-20	20.35 opqrst	46.05 jklmnopqr	43.25 b	8.90 zAB	8.30 qrstu	19.55 ijklm	3.75 stuvw	16.50 a
A-21	20.05 qrstuv	45.30 opqrstu	24.45 mno	9.85 xyzAB	8.48 pqrstu	22.75 efg	2.80 w	12.30 bc
A-22	21.15 lmnopqr	46.80 ghijklmno	24.10 no	8.45AB	7.75 tu	15.70 qrstuvwx	3.23 tuvw	11.75 bc
B-1	20.70 lmnopqrs	47.35 fghijklm	8.00 D	13.70 hijklmno	9.83 ghijklmno	14.55 stuvwx	12.65 a	1.25 fghi
B-2	26.65 a	59.75 a	14.15 wxyzA	16.65 e	11.60 cd	26.10 bcd	11.50 abcd	1.70 fghi
B-3	22.70 ghij	52.75 c	13.90 xyzAB	13.85 ghijklmno	11.55 cde	27.55 b	11.00 bcde	1.95 fghi
B-4	25.20 bc	56.30 b	12.80 yzABC	14.90 efghi	11.65 cd	24.35 cdefg	9.70 efghi	1.35 fghi
B-5	18.65 wx	39.90 z	12.95 yzABC	12.55 jklmnopqrst	9.55 ijklmnopq	24.35 cdefg	9.65 efghi	1.15 ghi
B-6	24.50 cde	57.20 b	12.80 yzABC	14.20 fghijkl	10.55 defghij	23.20 defg	10.95 bcde	1.30 fghi
B-7	19.00 uvwx	45.68 lmnopqrs	13.40 yzAB	12.40 klmnopqrstu	10.95 defgh	15.60 qrstuvwx	11.65 abcd	1.90 fghi
B-8	21.70 jklm	39.40 z	12.60 yzABC	15.20 efgh	10.20 fghijkl	25.00 bcdef	11.95 ab	1.20 fghi
B-9	21.25 lmnopq	48.20 efgh	10.30 CD	16.60 e	8.80 mnopqrstu	16.60 nopqrstu	10.30 defgh	1.85 fghi
B-10	18.65 wx	39.90 z	12.40 yzABC	19.15 d	14.50 a	32.25 a	8.95 fghijk	1.00 hi
B-11	21.60 jklmn	43.95 stuvw	13.60 yzAB	14.00 ghijklm	10.70 defghij	23.60 defg	9.30 fghi	1.40 fghi

Table 4 continued

Accession no.	Quantitative morphological characters of wild *Rosa* accessions							
	PB (mm)	FlD (mm)	PdL (mm)	HL (mm)	HW (mm)	AN (*n*)	PrL (mm)	HNI (*n*)
B-12	26.40 ab	52.80 c	16.75 tuvw	14.30 fghijk	11.15 cdefg	22.65 efgh	7.55 klm	1.25 fghi
B-13	19.20 tuvwx	48.55 defg	14.70 vwxyzA	12.50 jklmnopqrst	10.50 defghij	15.80 qrstuvwx	7.75 jkl	1.00 hi
B-14	20.20 pqrstu	44.25 rstuv	14.55 vwxyzA	12.40 klmnopqrstu	10.55 defghij	15.95 pqrstuvwx	8.88 ghijk	1.00 hi
B-15	20.80 lmnopqrs	43.45 uvwx	26.85 ijklm	12.10 mnopqrstuv	10.25 efghijk	16.55 nopqrstu	10.85 bcde	1.75 fghi
B-16	20.20 pqrstu	47.30 fghijklm	25.30 klmno	13.50 hijklmnop	10.90 defgh	16.80 mnopqrst	6.20 mnop	1.00 hi
B-17	17.35 y	36.95 A	12.05 ABC	13.20 hijklmnopq	9.05 klmnopqrst	11.60 y	10.40 cdef	1.15 ghi
B-18	21.90 ijkl	45.80 klmnopqrs	21.00 pq	14.30 fghijk	9.15 klmnopqrs	15.10 rstuvwx	10.35 defg	1.85 fghi
B-19	21.40 klmnop	46.15 ijklmnopq	27.20 hijkl	12.20 lmnopqrstu	9.15 klmnopqrs	13.05 xy	9.85 efgh	1.80 fghi
B-20	20.50 mnopqrs	43.80 tuvw	18.30 rst	11.00 rstuvwxy	8.95 klmnopqrstu	13.55 vwxy	9.55 efghi	1.25 fghi
B-21	24.50 cde	40.75 yz	12.20 zABC	12.73 jklmnopqrs	10.50 defghij	26.85 bc	11.85 abc	1.65 fghi
B-22	19.65 stuvw	41.85 xy	16.90 stuv	13.23 hijklmnopq	8.93 klmnopqrstu	14.00 tuvwxy	8.35 ijkl	2.40 fgh
C-1	18.15 xy	44.65 qrstuv	14.68 vwxyzA	24.14 bc	10.88 defghi	27.60 b	5.78 opqr	3.45 fg
C-2	20.25 opqrst	44.75 pqrstuv	13.20 yzAB	25.75 b	11.23 cdef	26.85 bc	5.98 nopq	3.20 fgh
C-3	22.80 ghij	49.35 de	12.55 yzABC	24.40 bc	10.23 efghijkl	25.55 bcde	6.90 lmno	3.50 f
D-1	18.88 vwx	45.73 klmnopqrs	50.70 a	0.00 D	0.00 w	0.00 z	7.05 lmno	0.00 i
E-1	24.90 cd	42.15 wxy	16.50 tuvwx	5.60 C	4.45 v	1.00 z	5.05 pqrs	2.70 fgh
F-1	19.98 rstuv	47.50 efghijkl	16.78 stuvw	19.48 d	13.40 ab	16.03 opqrstuvw	10.20 defgh	1.55 fghi
F-2	20.25 opqrst	43.15 vwx	17.65 stu	23.45 c	10.70 defghij	14.55 stuvwx	7.35 lmn	3.00 fgh
F-3	18.65 wx	39.85 z	17.50 stu	28.45 a	14.70 a	14.35 stuvwxy	9.15 fghij	3.35 fg
F-4	24.05 cdef	48.40 defgh	13.35 yzAB	24.80 bc	11.10 cdefgh	15.75 qrstuvwx	0.00 x	2.20 fghi
F-5	23.00 fghi	47.95 efghi	20.50 pqr	22.80 c	12.35 bc	16.40 nopqrstuv	9.85 efgh	2.95 fgh
F-6	23.50 efgh	59.65 a	15.08 uvwxy	26.15 b	10.00 fghijklm	15.70 qrstuvwx	10.95 bcde	2.20 fghi
F-7	22.15 c	49.00 def	19.45 qrs	12.95 ijklmnopqr	10.25 efghijk	18.80 lmnop	7.15 lmno	1.30 fghi
F-8	22.50 hijk	46.20 ijklmnopq	14.75 vwxyz	16.10 ef	10.05 fghijklm	13.80 uvwxy	8.85 hijk	1.75 fghi
F-9	23.90 defg	50.20 d	11.30 BC	15.85 efg	9.85 ghijklmn	14.15 stuvwxy	10.90 bcde	1.50 fghi
F-10	20.25 opqrst	45.35 nopqrst	29.70 fgh	12.60 jklmnopqrst	9.55 ijklmnopq	16.75 mnopqrst	8.95 fghijk	1.75 fghi

Accession numbers/codes are given in Table 1

Abbreviations for quantitative morphological characters are given in Table 3

Values followed by the same lower/uppercase letters within the same column are not different at $p > 0.05$

(Table 4). Mean values for hip length (HL) ranged from 5.6 mm in *R. multiflora* accession E-1 to 28.45 mm in *R. macrophylla* accession F-3, and those for hip width ranged from 4.45 mm in *R. multiflora* accession E-1 to 12.35 mm in *R. macrophylla* accession F-5. Hips did not develop in *R. foetida* accession D-1. HNI ranged from zero in *R. foetida* accession D-1 to 17.75 in *R. moschata* A-18. The highest number of achenes per hip were found in *R. moschata* accession B-10, and the lowest number was found in *R. multiflora* accession E-1 (Table 4). Flower size, fruit size, and achene number should probably be among the first characteristics to be considered by the rose breeders as goals in selection programs, with the aim to achieve more benefits from the presence of flowers, fruits, and achenes as these plant parts have the maximum aromatic potential. This aromatic potential is especially important in the perfume and cosmetics industry (De Groot and Schmit 2016) and the pharmaceutical industry (Larsen et al. 2003; Nagatomo et al. 2015).

Analysis of our collected samples of wild *Rosa* accessions revealed a wide variation in leaflet number, ranging from 3 to 13 leaflets. The leaflet number in *R. moschata* was found to range from three to nine, which corresponds with the earlier documented range of three to seven leaflets for this species (Singh et al. 2017). In *R. canina*, the leaflet number ranged from three to seven leaflets, which is not in agreement the earlier reported range of five to seven leaflets as documented in different floras. Similarly, in *R. macrophylla*, leaflet number ranged from 3 to 13 leaflets, which is not consonance with the earlier range of 5–13 leaflets recorded for this species in different floras.

Correlations among morphological traits (quantitative and qualitative) in the studied wild *Rosa* accessions of the Western Himalayan Region, India are shown in ESM Table 1. Given the economic importance of the leaves, flower hips (fruits) and achenes of wild *Rosa* species, we determined the correlations among various morphological quantitative traits (Table 5). According to the results of our study, leaflet length showed a significant positive correlation with leaflet width ($r = 0.922$), petiole length ($r = 0.830$), pedicel length ($r = 0.670$), prickle length ($r = 0.840$), hip number per inflorescence ($r = 0.862$) and petal color ($r = 0.572$) and a negative correlation with flower fragrance ($r = -0.840$). Petal length, petal breadth and flower diameter had a strong positive correlation with each other ($r = 0.896$ and 0.635, respectively). Flower diameter showed a negative correlation with pedicel length ($r = -0.100$). Hip length showed a strong positive correlation with hip width ($r = 0.732$), and hip width displayed a strong negative correlation with pedicel length ($r = -0.605$) and hip color ($r = -0.690$). Hip number per inflorescence showed a positive correlation with leaflet length ($r = 0.862$), leaflet breadth ($r = 0.749$), petiole length ($r = 0.655$) and pedicel length ($r = 0.642$) and a strong negative correlation with prickle length ($r = -0.794$). No comparable morphometric studies on wild *Rosa* species have been conducted to date that can be used for comparison with the pattern observed in the present study.

Principal component analysis

Principal component analysis has been previously used to study the morphometric variations in wild rose populations from Tunisia (Cheikh-Affene et al. 2015). In our study, the results of PCA on the morphological traits indicated that the first six principal components (PCs) accounted for 65.44% of the total variation (Table 6). According to Reim et al. (2012), such results indicate a very high level of morphological variation, symbolizing a high genetic diversity between the accessions and suggesting that in terms of full characterization of the accession, evaluation of the different morphological traits is still necessary. The first two PCs explained about 41.70% of the total observed variability (Fig. 3), with PC1 presenting 30.36% of the variation and featuring maximum values for a number of characters, such as leaflet length, leaflet breadth, petiole length, pedicel length, hip length, hip width, prickle length, number of hips per inflorescence, prickle shape, leaf hairs on adaxial surface, leaflet shape, leaflet apex and base, bract number, bract shape, sepal edge, sepal permanency, sepal apex, petal apex, petal color, flower fragrance, style nature, anther color, hairs on hips, hip color, and hip shape. PC2 explained 11.34% of the total variance and was related to stipule length, stipule breadth, sepal length, sepal breadth, and prickle shape.

Table 5 Two-tailed Pearson's correlation between various quantitative morphological characters of wild *Rosa* accessions from the Western Himalaya Region, India

	LfL	LfB	PtL	StL	StB	SL	SB	PL	PB	FlD	PdL	HL	HW	AN	PrL
LfL	1.000	–	–	–	–	–	–	–	–	–	–	–	–	–	–
LfB	0.922**	1.000	–	–	–	–	–	–	–	–	–	–	–	–	–
PtL	0.830**	0.850**	1.000	–	–	–	–	–	–	–	–	–	–	–	–
StL	0.385	0.552	0.594**	1.000	–	–	–	–	–	–	–	–	–	–	–
StB	− 0.200	− 0.024	0.024	0.660**	1.000	–	–	–	–	–	–	–	–	–	–
SL	0.236	0.263	0.270	0.502	0.402	1.000	–	–	–	–	–	–	–	–	–
SB	− 0.150	0.006	0.014	0.483	0.681**	0.476	1.000	–	–	–	–	–	–	–	–
PL	0.000	0.013	− 0.015	− 0.024	0.006	0.043	0.124	1.000	–	–	–	–	–	–	–
PB	− 0.260	− 0.215	− 0.191	0.048	0.116	0.068	0.236	0.759**	1.000	–	–	–	–	–	–
FlD	− 0.080	− 0.071	− 0.083	− 0.042	0.089	0.109	0.160	0.896**	0.635**	1.000	–	–	–	–	–
PdL	0.670**	0.603**	0.624**	0.142	− 0.288	0.072	− 0.079	− 0.075	− 0.315	− 0.100	1.000	–	–	–	–
HL	− 0.280	− 0.187	− 0.183	0.277	0.527	0.532	0.314	0.066	0.134	0.147	− 0.557	1.000	–	–	–
HW	− 0.390	− 0.404	− 0.378	− 0.107	0.187	0.153	0.000	0.043	0.119	0.097	− 0.605**	0.732**	1.000	–	
AN	− 0.010	0.031	− 0.096	− 0.062	− 0.130	0.112	− 0.055	0.239	0.114	0.143	− 0.247	0.312	0.539	1.000	
PrL	− 0.840**	− 0.766**	− 0.690**	− 0.329	0.302	− 0.138	0.174	− 0.025	0.216	0.097	− 0.580**	0.295	0.393	0.026	1.000

Abbreviations for quantitative morphological characters are given in Table 3

**Correlation coefficient significant at $p = 0.01$ with value of ≥ 0.561

Table 6 Eigen values and cumulative variance for six major factors obtained from principal component analysis and significant parameters within each component

Morphological characters	Principal component (PC) analysis					
	PC1	PC2	PC3	PC4	PC5	PC6
LfL	− 0.890**	0.307	− 0.084	0.209	0.002	− 0.044
LfB	− 0.784**	0.452	− 0.039	0.126	− 0.101	0.054
PtL	− 0.707**	0.466	0.056	0.215	− 0.024	0.021
StL	− 0.141	0.781**	0.051	0.136	− 0.227	0.207
StB	0.481	0.747**	0.113	0.022	− 0.138	0.017
SL	0.040	0.646**	− 0.310	0.133	− 0.095	− 0.056
SB	0.342	0.723**	0.102	− 0.164	0.001	0.220
PL	0.052	0.094	− 0.511**	− 0.217	0.568**	0.414
PB	0.344	0.042	− 0.377	− 0.140	0.424	0.439
FlD	0.138	0.148	− 0.469	− 0.260	0.584**	0.323
PdL	− 0.696**	0.156	0.365	0.044	0.213	− 0.030
HL	0.536**	0.384	− 0.529**	0.118	− 0.321	− 0.133
HW	0.519**	− 0.140	− 0.593**	0.172	− 0.366	− 0.128
AN	− 0.026	− 0.170	− 0.527**	− 0.441	− 0.337	0.075
PrL	0.829**	− 0.160	0.068	− 0.264	0.036	− 0.129
HN	− 0.918**	0.012	− 0.166	0.133	0.013	0.003
PrS	0.701**	0.602**	0.040	− 0.011	− 0.183	− 0.092
LfN	0.416	0.305	0.168	0.170	0.525**	− 0.129
LfHab	− 0.092	0.071	0.104	0.304	0.059	0.413
LfHad	− 0.789**	0.432	− 0.044	− 0.016	0.080	− 0.013
LfGab	− 0.218	− 0.360	0.267	− 0.054	− 0.440	0.324
LfM	0.498	0.473	0.226	0.176	0.271	− 0.367
LfMG	− 0.148	− 0.230	0.330	0.521**	0.214	− 0.339
LfS	0.746**	0.446	0.184	0.227	− 0.109	− 0.032
LfAp	0.609**	− 0.012	0.060	− 0.016	0.381	0.095
LfBa	0.847**	0.140	− 0.003	− 0.082	− 0.081	0.087
RPr	0.407	0.490	− 0.049	0.508**	0.167	− 0.175
RG	− 0.135	− 0.085	0.133	0.354	0.018	0.488
StS	− 0.178	0.052	0.194	0.284	0.109	0.517**
StA	− 0.388	− 0.050	− 0.294	0.037	− 0.101	0.007
StH	0.477	− 0.088	0.032	0.492	0.180	− 0.017
StG	− 0.013	− 0.118	0.126	0.137	− 0.063	− 0.038
HyH	− 0.322	0.214	0.353	− 0.375	0.049	− 0.275
HyG	0.112	0.308	0.526**	− 0.568**	− 0.018	0.072
PdH	0.312	− 0.189	0.045	0.410	0.089	0.286
PdG	0.247	0.227	0.304	0.064	− 0.225	0.545**
BrN	0.840**	− 0.308	− 0.213	0.155	− 0.032	− 0.191
BrS	− 0.730**	− 0.455	0.272	− 0.054	0.106	0.022
SpF	0.151	− 0.159	− 0.227	− 0.111	0.081	− 0.129
SpE	− 0.836**	0.200	0.084	− 0.123	0.011	0.072
SpP	0.917**	− 0.197	0.146	− 0.030	0.139	− 0.167
SpA	0.575**	0.253	− 0.050	− 0.013	− 0.285	0.074
SpG	0.132	− 0.113	0.446	− 0.301	0.089	0.127

Table 6 continued

Morphological characters	Principal component (PC) analysis					
	PC1	PC2	PC3	PC4	PC5	PC6
SpPr	− 0.157	− 0.312	0.339	0.019	− 0.571**	0.243
PA	0.731**	− 0.198	0.417	0.048	0.101	− 0.019
PC	− 0.667**	0.271	0.138	− 0.309	0.163	− 0.035
FlF	0.884**	0.118	0.296	− 0.251	− 0.005	0.019
Sty	0.892**	0.080	0.206	− 0.126	− 0.039	0.145
FlC	− 0.069	0.467	− 0.120	− 0.315	− 0.194	0.101
WhS	− 0.101	0.219	0.010	0.154	0.074	0.158
AnC	− 0.626**	0.371	− 0.318	− 0.179	0.114	− 0.240
HH	− 0.554**	0.493	0.322	0.032	− 0.110	− 0.241
HG	0.382	0.118	0.111	− 0.668**	0.069	− 0.059
HC	− 0.819**	0.100	0.269	− 0.153	0.242	− 0.119
HS	0.569**	0.422	0.307	0.066	0.030	0.085
Eigen value	16.700	6.236	4.242	3.319	2.932	2.565
% Variance	30.361	11.339	7.713	6.034	5.331	4.663
% Cumulative	30.361	41.700	49.413	55.447	60.778	65.441

Abbreviations for morphological characters are given in Table 3

**Eigen values significant > 0.50

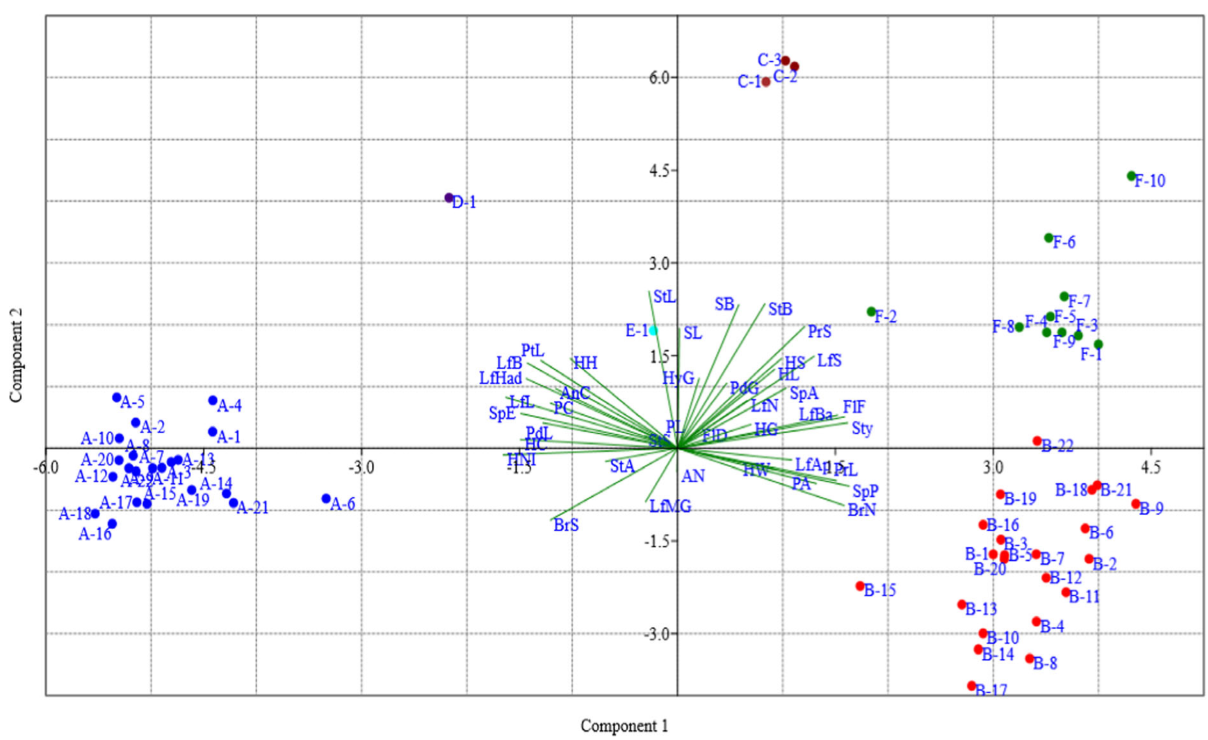


Fig. 3 Principal component analysis plot of wild *Rosa* accessions from the Western Himalaya Region, India based on the first two components for morphological characters. Abbreviations of morphological traits are given in Table 3.Accession numbers/codes are given in Table 1.

Cluster analysis

The dendrogram obtained with the UPGMA method exhibits diverse hierarchical levels of wild *Rosa* accessions and is separated into two main clusters (Fig. 4), namely Cluster A and Cluster B, on the basis of the long pedicel length, absence of hips, leaflet number, petal color and flower fragrance possessed by *Rosa foetida* var. *persiana* of cluster B. Cluster A can be seen to encompass accessions of five species of wild *Rosa* (*R. moschata*, *R. multiflora*, *R. canina*, *R. macrophylla*, *R. webbiana*) and is divided into two groups A1 and A2 on the basis of the shorter prickle length, hip number per inflorescence, ovate-to-lanceolate leaflet shape, connate style, roundish hip shape and reddish-orange hip color of *R. moschata* of group A1. Group A2 segregates into subgroup A2a and A2b on the basis of the shorter hip length and width, smaller number of achenes, presence of only two pinna along the sepal margins, and connate and glabrous style possessed by *R. multiflora* of subgroup A2a. Subgroup A2b forms two more subgroups, A2ba and A2bb, based on the shorter leaflet length and breadth, stipule breadth, and stipule length of *R. webbiana*. *R. canina* accessions of subgroup A2ba differ from *R. macrophylla* accessions in having hooked prickles, an absence of glands on hips and pedicel, bract number (1), deciduous sepals and urceolate-to-ovoid hip shape, which was also justified by their position in the dendrogram.

All other accessions of different species were resolved into relatively homogenous groups, which suggested that morphological distinction and species delimitation in wild *Rosa* species is extremely difficult, possibly due to their morphological similarity together with extensive hybridization in the wild (Guoliang 2003).

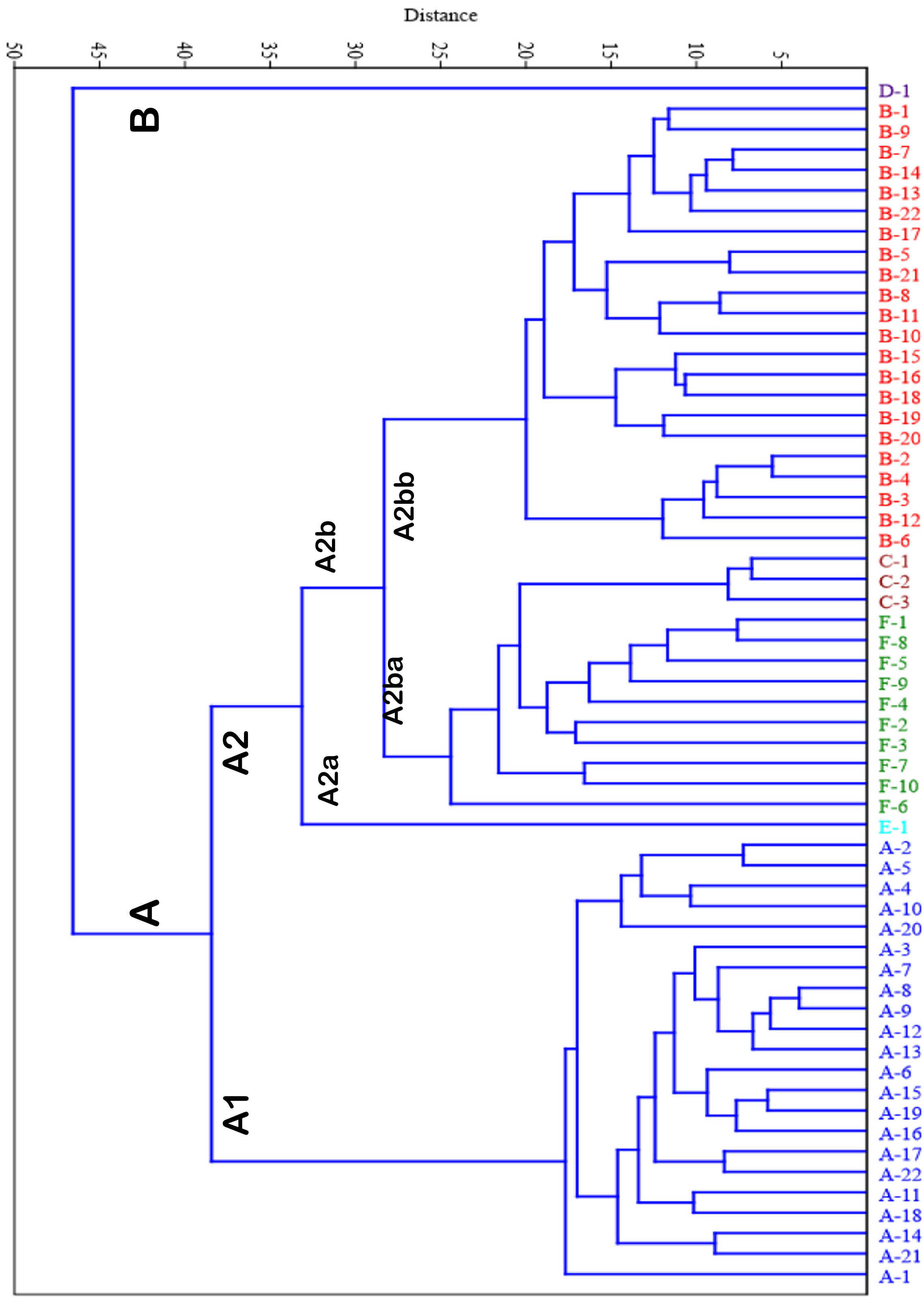
Fig. 4 Dendrogram of grouping for the 59 accessions belonging to the six wild *Rosa* species collected from the Western Himalaya Region, India using the PAST 3.22 software program (Hammer et al. 2001) ▶

Discussion

In this study we found wild roses to be distributed from the subtropical areas of Kathua, J&K (accession A-1, 792 m a.s.l.) to the higher arid regions of Nyoma, Leh, Ladakh (accession B-14, 4504 m a.s.l.), indicating the robustness and adaptability of these species to this wide range of climatic conditions. The altitudinal range of wild *Rosa* species in the Indian Himalaya Region has also been recorded in earlier studies (Hooker 1879; Gupta 1979; Collet 1984; Sharma and Jamwal 1988; Pal 1991).

Rosa species collected from the Western Himalayan Region, India, in this study portrayed a wide range of morphological variability in both quantitative and qualitative characters. Clustering analysis also proved that the morphological variability in the accessions of the different *Rosa* species is of a continuous nature and affirmed strong overlaps between the different traits. The similarity observed in the characters relating to flower, fruit, and leaflet morphology in some accessions of *R. macrophylla* and *R. webbiana* in our study hint towards the possibility that these two species frequently undergo hybridization in the wild, thus making their identification difficult, as encountered in this study. However, a few traits that can be used to discriminate these two species are reported in the literature. One example is the presence of a caudate sepal apex and long pedicel length in *R. macrophylla*; however, these characters are also found in the accessions of *R. webbiana*. A similar taxonomic problem was also reported at the diploid level by Lewis (1962) in *R. blanda* and *R. woodsii*, but the problem is much more complex at the polyploidy level as polyploidy is very common in wild rose (Fougere-Denezan et al. 2015). Therefore, molecular approaches are also required to achieve a proper resolution of species identification in this region.

The dendrogram obtained with the UPGMA method categorized accessions within a species into different groups and subgroups (Fig. 4), suggesting that there is genetic variation which might be the outcome of unrestricted crossing between wild relatives of different *Rosa* species. The intermediates that result from this genetic exchange could be exploited through direct selection to obtain higher yield of the particular trait being studied. Similar results have been recorded in apple and papaya by various researchers (Coart et al. 2003; Mratinic and Aksic 2012; Chavez-Pesqueria et al. 2014). According to Vanhala et al. (2004), wild accessions contain important variations in their genetic makeup that are vital for the development of highly improved modern cultivars


Distance
50
45
40
35
30
25
20
15
10
5
B
A
A1
A2
A2a
A2b
A2ba
A2bb
D-1
B-1
B-9
B-7
B-14
B-13
B-22
B-17
B-5
B-21
B-8
B-11
B-10
B-15
B-16
B-18
B-19
B-20
B-2
B-4
B-3
B-12
B-6
C-1
C-2
C-3
F-1
F-8
F-5
F-9
F-4
F-2
F-3
F-7
F-10
F-6
E-1
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A-21
A-1

characterized by domestication and narrow genetic backgrounds. For the patenting and registration of varieties, a description of the morphological character is the customary methodology accepted from a legal point of view (Badeness et al. 1998).

We determined that some of the wild *Rosa* species collected have many favourable traits and thus would be good sources of germplasm for use in breeding programs. The comparatively smaller leaflet size in *R. webbiana* accessions indicate an adaptive response to water stress and drought, and this trait can be manipulated in breeding programs aimed at developing drought-resistant varieties. Accessions F-5, F-3 and A-18 can be directly selected for the production of long hips, wide hips and a higher number of hips per inflorescence, respectively. Similarly, as the petals of roses have immense economic potential in the aroma sector, larger flower size can be obtained by the direct selection of *R. webbiana* accession B-2. Morphological markers have been used for germplasm characterization in earlier studies (Veasey et al. 2001; Rakonjac et al. 2010), but morphological traits alone may not be sufficient for determination of the relationship among species (Llyod et al. 1992). Molecular markers, such as randomly amplified polymorphic DNA (RAPD; Wen et al. 2004), amplified fragment length polymorphism (AFLP; Panwar et al. 2015), inter-simple sequence repeat (ISSR; Ogras et al. 2017) and start codon targeted markers (SCoT; Agarwal et al. 2019), have been used to study the genetic diversity in wild *Rosa*. Jabbarzadeh et al. (2013) used ISSR analysis to study *R. canina* and *R. moschata* and found $> 53\%$ genetic similarity between these two species. To date, no genetic diversity assessment has been conducted on *R. webbiana* and *R. macrophylla*. A genetic diversity assessment of our collection using molecular markers would provide valuable information for further characterizing the genetic background of the Western Himalayan wild *Rosa* species.

The results of our study demonstrate that the wild species of *Rosa* carry important agronomic traits, such as leaflet length, flower diameter, number of achenes, number of hips per inflorescence and length and width of hips, that can be used to further improve the quality of cultivated *Rosa* species by introgressive hybridization. Our findings on wild *Rosa* species prove the complex nature of this morphologically variable genus. It is therefore necessary to make due efforts for the continuous collection, conservation, characterization and evaluation of new accessions and new species from the wild, with a particular focus on averting the loss of wild *Rosa* germplasm. In addition, the creation of a *Rosa* germplasm repository is essential. *Rosa* germplasm from wild genotypes are needed to expand the diversity of this important genetic resource and to utilize the genetic potential of these genotypes for improvement of traits needed for adaptation to various conditions in near future.

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References

Agarwal A, Gupta V, Haq S, Jatav PK, Kothari SL, Kachhwaha S (2019) Assessment of genetic diversity in 29 rose germplasm using SCoT marker. J King Saud University–Science 31(4):780–788.

Ambasta SP (1986) The useful plants of India. Publication and Information Directorate, CSIR, New Delhi

Andrews HC (1805) Roses, or, a monograph of the genus *Rosa*: containing colored figures of all known species and beautiful varieties. R Taylor and Co, London

Badeness ML, Martinez-Calvo J, Llacer G (1998) Analysis of apricot germplasm from the European ecogeographical group. Euphytica 102:93–99

Baker JG (1869) A monograph of the British roses. J Linn Soc Lond Bot 11:197–243

Bamber CJ (1976) Plants of the Punjab, North West Frontier Province and Kashmir. Bishen Singh Mahendra Pal Singh, Dehra Dun

Boskabady MH, Kiani S, Rakshandah H (2006) Relaxant effects of *Rosa damascene* on guinea pig tracheal chains and its possible mechanism(s). J Ethnopharmacol 106:377–382

Broertjes C, van Harten AM (1978) Application of mutation breeding methods in the improvement of vegetatively propagated crops. Elsevier, Amsterdam

Chavez-Pesqueira M, Suarez-Montes P, Castillo G, Nunez Farfan J (2014) Habitat fragmentation threatens wild populations of *Carica papaya* (Caricaeae) in a lowland rainforest. Am J Bot 101:1092–1101

Cheikh-Affene ZB, Haouala F, Harzallah-Skhiri F (2015) Morphometric variation and taxonomic identification of thirteen wild rose populations from Tunisia. Acta Bot Croat 74:1–17

Chowdhery HJ, Wadhwa BM (1984) Flora of Himachal Pradesh analysis, vol 1. B.S.I. Publication, Delhi
Coart E, Vekemanas X, Smudlers MJM, Wagner I, Huylenbroeck VJ, van Bockstaele E (2003) Genetic variation in endangered apple (*Malus sylvestris* (L) Mill.) in Belgium as revealed by amplified fragment length polymorphism and microsatellite markers. Mol Ecol 12:845–857
Collet H (1984) Flora simlensis. International Book Distributors, Dehra Dun
De Cock K (2008) Genetic diversity of wild roses (*Rosa* spp.) in Europe, with an in-depth morphological study of Flemish populations. PhD thesis. Faculty of Bioscience Engineering, Ghent University, Ghent
De Groot AC, Schmidt E (2016) Essential oils: contact allergy and chemical composition. CRC Press, Boca Raton
Debener T, Linde M (2009) Exploring complex ornamental genomes. The rose as a model plant. Crit Rev Plant Sci 28:267–280
Demir F, Ozcan M (2001) Chemical and technological properties of rose (*Rosa canina* L.) fruits grown wild in Turkey. J Food Eng 47:333–336
Dhyani D, Singh S (2014) Potential wild rose germplasm of Western Himalayas—conservation, evaluation and registration. Indian J Agr Sci 84:229–235
Duthie JF (1971) Flora of the Upper Gangetic Plain: and of the adjacent Shiwalik and Sub-Himalayan tracts, vol. 1. International Book Distributors, Uttarakhand
eFI (2018) Eflora of India. https://sites.google.com/site/efloraofindia. Accessed 23 Aug 2018
eFloras (2019) Missouri Botanical Garden, St. Louis, MO & Harvard University Herbaria, Cambridge. http://www.efloras.org Accessed 22 Feb 2019
Fougere-Denezan M, Joly S, Bruneau A, Gao XF, Zhang LB (2015) Phylogeny and biogeography of wild roses with specific attention to polyploids. Ann Bot 115:275–291
Gao X, Uggla M, Rumpunen K (2005) Antioxidant of dried and boiled rose hips. In: Nybom H, Rumpunen K (eds) Proc 1st Int Rose Hip Conf, 7–10. September 2004. International Society for Horticultural Science, pp 239–249
Gu C, Robertson KR (2003) *Rosa* L. In: FoCe Team (ed) Flora of China. Missouri Botanical Garden Press, St. Louis, pp 339–381
Guoliang W (2003) Ancient Chinese roses. In: Roberts A, Debener T, Gudin S (eds) Encyclopedia of rose science. Elsevier, Amsterdam, pp 387–395
Gupta BL (1979) Forest flora of the Chakrata, Dehra Dun and Saharanpur Forest Division, United Provinces. Jayyed Press, Delhi, pp 220–223
Gurbuz I, Ustun O, Yesilada E, Sezik E, Kutsal O (2003) Antiulcerogenic activity of some plants used as folk remedy in Turkey. J Ethnopharmacol 88:93–97
Hammer O, Harper DAT, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontol Electron 4:9
Hodisan T, Socaciu C, Ropan I, Neamtu G (1997) Carotenoid composition of *Rosa canina* fruits determined by thin-layer chromatography and high-performance liquid chromatography. J Pharm Biomed 16:521–528
Hooker JD (1879) Flora of British India, vol 2. L. Reev & Co Ltd, Kent
Hummer KE, Janick J (2009) Rosaceae: taxonomy, economic importance, genomics. In: Folta KM, Gardiner SE (eds) Plant genetics and genomics 6: genetics and genomics of Rosaceae. Springer, New York, pp 339–351
Jabbarzadeh Z, Khosh-khui M, Salehi H, Shahsavar AR, Saberivand A (2013) Assessment of genetic relatedness in roses by ISSR markers. World Appl Sci J 28:2085–2090
Kachroo P, Bansilal S, Dhar U (1977) Flora of Ladakh: an ecological and taxonomical appraisal. International Book Distributors, Dehradun
Kanli FA, Kazaz S (2009) Biotechnology of roses: progress and future prospects. Turk J For 1:167–183
Karakaya S, Kavas A (1999) Antimutagenic activities of some foods. J Sci Food Agric 79:237–242
Khatamsaz M (1992) Flora of Iran (Rosaceae) (Vol 6). Research Institute of Rangeland and forests, Tehran
Koobaz P, Kermani MJ, Hosseini ZS, Khatamsaz M (2009) Inter and Intraspecific morphological variation of four Iranian rose species. Global Science Books, Ikenobe, Kagawa
Larsen E, Kharazmi A, Christensen LP, Christensen SB (2003) An antiinflammatory galactolipid from rose hip (*Rosa canina*) that inhibits chemotaxis of human peripheral blood neutrophils in vitro. J Nat Prod 7:994–995
Lewis WH (1957) A monograph of the genus Rosa in North America east of the Rocky Mountains. PhD thesis. University of Virginia, Charlottesville
Lewis WH (1958) Minor forms of North American species of *Rosa*. Rhodora 60:237–243
Lewis WH (1962) A monograph of the genus Rosa in North America. *R. dulcissima*. Britonnia 14:65–71
Llyod A, Walbot V, Davis RW (1992) *Arabidopsis* and *Nicotiana* anthocyanin production activated by maize regulators R and Cl. Science 258:1773–1775
Marstrand K, Campbell-Tofte J (2016) The role of rose hip (*Rosa canina* L) powder in alleviating arthritis pain and inflammation–part II animal and human studies. Bot Targets Ther 6:59–73
Mratinic E, Aksic MF (2012) Phenotypic diversity of (*Malus* sp.) germplasm in south Serbia. Braz Arc Bio Tecnol 55:349–358
Nagatomo A, Nishida N, Fukuhara I (2015) Daily intake of rosehip extract decreases abdominal visceral fat in preobese subjects: a randomized, double-blind, placebo-controlled clinical trial. Diabetes Metab Syndr Obes 8:147–156
Ogras TL, Bastanlar EK, Metin OK, Kandemir I, Ozcelik H (2017) Assessment of genetic diversity of rose genotypes using ISSR markers. Turkish J Bot 41:347–355
Olsson A, Nybom H, Prentice HC (2000) Relationships between Nordic Dogroses (*Rosa* L. sect. *Caninae*, Rosaceae) assessed by RAPDs and elliptic Fourier analysis of leaflet shape. Syst Bot 25:511–521
Pal BP (1991) The rose in India. Publication and Information Division, ICAR, New Delhi
Panwar S, Singh KP, Sonah H, Deshmukh RK, Namita Prasad KV, Sharma TR (2015) Molecular fingerprinting and assessment of genetic diversity in rose (*Rosa* × hybrida). Indian J Biotechnol 14:518–524
Rakonjac V, Aksic MF, Nikolic D, Milatovic D (2010) Morphological characterization of ‘Oblacinska’ sour cherry by multivariate analysis. Sci Hortic 125:679–684

Rathore DS, Srivastava UC (1992) *Rosa* species (A bulletin). National Bureau of Plant Genetic Resources, Regional station, Phagli, Shimla

Reim S, Proft A, Heinz S, Hofer M (2012) Diversity of the European indigenous wild apple *Malus sylvestris* (L.) Mill. In the East Ore Mountains (Osterzgebirge), Germany: I morphological characterization. Genet Resour Crop Evol 59:1101–1114

Rein E, Kharazmi A, Winther K (2004) An herbal remedy, Hyben Vital (stand. powder of subspecies of *Rosa canina* fruits), reduces pain and improves general well being in patients with osteoarthritis. A double-blind, placebo-controlled, randomized trial. Phytomedicine 11:383–391

Rieseberg LH, Ellstrand NC (1993) What can molecular and morphological markers tell us about plant hybridisation? Crit Rev Plant Sci 12:213–241

Roman I, Stanila A, Stanila S (2013) Bioactive compounds and antioxidant activity of *Rosa canina* L biotypes from spontaneous flora of Transylvania. Chem Cent J 7:73

Schwager J, Richard N, Schoop R, Wolfram S (2014) A novel rose hip preparation with enhanced anti-inflammatory and chondroprotective effects. Mediators of Inflammation 2014:105710

Sharma BM, Jamwal PS (1988) Flora of Upper Liddar Valley of Kashmir Himalayas, vol 1. Scientific Publisher, Jodhpur, pp 197–198

Sharma BM, Kachroo P (1981) Flora of Jammu and plants of neighborhood, vol 1. Bishen Singh Mahendra Pal Singh, Dehra Dun

Singh G, Kachroo P (1976) Forest flora of Srinagar and Plants of neighborhood. Bishen Singh Mahendra Pal Singh, Dehra Dun

Singh S, Dhyani D, Nag A, Sharma RK (2017) Morphological and molecular characterization revealed high species-level diversity among cultivated, introduced and wild roses (*Rosa* sp.) of western Himalayan region. Genet Resour Crop Evol 64:515–530

Tejaswini MS Prakash (2005) Utilization of wild rose species in India. Acta Hortic 690:91–96

Tumbas VT, Canadanovic-Brunet JM, Cetojevic-Simin DD, Cetkovic GS, Dilas SM, Gille L (2011) Effect of rose hip (*Rosa canina* L.) phytochemicals on stable free radicals and human cancer cells. J Sci Food Agric 92:1273–1281

Vanhala TK, van Rijn CPE, Buntjer J, Stam P, Nevo E, Poorter H, van Eeuwijk FA (2004) Environmental, phenotypic and genetic variation of wild barley (*Hordeumspontaneum*) from Israel. Euphytica 137:297–304

Veasey EA, Schammas EA, Vencovsky R, Martins PS, Bandel G (2001) Germplasm characterization of Sesbania accessions based on multivariate analysis. Genet Resour Crop Evol 48:79–90

Warholm O, Skaar S, Hedman E (2003) The effects of standardized herbal remedy made from subtype of *Rosa canina* in patients with osteoarthritis: a double-blind, randomized, placebo-controlled clinical trial. Curr Ther Res 64:21–31

Wen XP, Pang XM, Dang XY (2004) Characterization of genetic relationship of *Rosa roxburghii* Tratt. and its relatives using morphological traits RAPD and AFLP markers. J Hortic Sci Biotech 79:189–196

Werlemark G, Nybom H (2001) Skewed distribution of morphological character scores and molecular markers in three interspecific crosses in Rosa section Caninae. Hereditas 134:1–13

Winther K (2014) Low-dose seed and shell powder from rosehip (*Rosa canina*) can alleviate symptoms of osteoarthritis and reduce C-reactive protein in patient suffering from osteoarthritis (abstract). Osteoarthr Cartilage 22:321–322

Wissemann V (2003) Conventional taxonomy wild (roses). In: Roberts AV, Debener T, Gudin S (eds) Encyclopedia of rose science. Elsevier, Amsterdam, pp 111–117

Zlesak DC (2007) Rose. In: Anderson NO (ed) Flower breeding and genetics: issues, challenges and opportunities for the 21st Century, Springer, Dordrecht, pp 695–737