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Original article

Threatened *Prunus arabica* in an ancient volcanic protected area of Saudi Arabia: Floristic diversity and plant associations

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ABSTRACT

Prunus arabica (Oliv.) Meikle is an endangered shrub with a restricted distribution, which inhabits banks of flood flow channels in small sites of ancient volcanic activity dominated by black basaltic boulders within the Harrat Al-Harrah protectorate, Northern Saudi Arabia. It is with limited information about its ecology and hence, the present study is focusing on its phytosociological behavior and ecological features. The multi-methodological approach comprised species description, vegetation sampling and soil composition of 9 study sites at Harrat Al-Harrah protectorate. The application of TWINSPAN, DCA and CCA multivariate analyses led to identify 3 vegetation groups (VGI: *Pulicaria undulata-Prunus arabica*, VGII: *Prunus arabica–Artemisia seiberi*, VGIII: *Artemisia seiberi-Achillea fragrantissima*) associated with the distribution of *P. arabica*. The environmental variables that affect *P. arabica* and its main ecological features had been estimated and discussed. The present study concludes that the main reasons for its threatened and endangerment are seemingly due to overgrazing, poor rainfall, drought, shifting and destruction of its suitable habitat area.

1. Introduction

During the last 60 years, considerable changes have occurred in the natural habitat and landscape of Saudi Arabia. Modern firearms, field vehicles, ambitious development programs in various fields, especially in the last two decades, have left clear marks on the country landscape. Moreover, there is an increasing threat to the country's magnificent marine and terrestrial resources. Therefore, in Saudi Arabia much importance is given to *in situ* conservation which mainly aims to maintain and recover viable populations of wild species in nature within their known natural ranges (Abuzinada, 2003). This is being achieved through a creating a system of protected areas in order to effectively protect, develop and maintain representative samples of the various biotopes in the country. Harrat Al-Harrah is such a protected area which includes broad vegetated wadis, smaller vegetated drainage lines, silty depressions, undulating gravel hills, steep sided hills (jibals) and old volcanic cones (Seddon et al., 1997). In general, tree vegetation is lacking in this area except for a few tall shrub component represented by *Haloxylon persicum* on the deep sand deposits and common low shrubs e.g. *Anabasis* spp., *Artemisia* spp., *Calligonum comosum*, *Pulicaria crispa, Achillea fragrantissima* and *Prunus arabica*.

The genus *Prunus* belonging to the subfamily Prunoidae in the Rosaceae family includes around 400 plant species that yield a variety of raw materials for horticulture, ornamental, food, and pharmaceutical industries (Ozcelik et al., 2012). Most of these species are originally from Asia or Southern Europe (Davis, 1971), such as peach (*Prunus persica).* In Saudi Arabia, the genus is represented by only two species, *Prunus arabica* and *Prunus korshinskyi* (Chaudhary, 1999–2001). *P. arabica* is one of the endangered plants in Saudi Arabia due to excessive grazing, habitat loss and poor regeneration capability. It is growing in arid and semi arid regions, on limestone and volcanic rocky slopes, mountains and savannas; often along riversides, and gorges, dry gullies and wadis habitat, at elevations between 500 and 2700 m. It grows in well-drained light (sandy), medium (loamy) and heavy (clay) soils. Suitable pH: acid, neutral and basic (alkaline) soils. It can grow in

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semi-shade (light woodland) or no shade area. It prefers dry or moist soil (Bown, 1995).

P. arabica is an important soil controller plant (phytogenic plant), which has a distinctive broom like habit, with early deciduous leaves during drought season and the lack of short shoots. It is known to local inhabitants by the arabic name 'Luwaiza'. There is very few information about this plant in Saudi Arabia. *P. arabica* is so far, recorded from the, Harrat Al-Harrah in few patches along the banks of flood flow of three channels or small wadis only, with area about 7 m × 50 m per channel.

In this paper, we studied plant associations with *P. arabica* by analyzing its phytosociology in terms of floristic and vegetation structure with associated species and the environmental features. This assessment considers the first step to conserve *P. Arabica*; as an endangered plant.

2. Materials and methods

2.1. Study area

Harrat Al-Harrah was primarily created to protect important relict breeding populations as well as to conserve a representative portion of the Harrat biotope (olivine basalt lava field). It is one of the largest Harrats in Saudi Arabia. The southern portion, the main Harrat field measuring about 45,000-km^2, extends towards north up to Jordan and Syrian borders. Harrat Al-Harra is located between Al-Jouf and Turaif, north of Saudi Arabia, close to Jordan border (N31°02.358′ E039°23.608′). The Board of Directors of the National Commission for Wildlife Conservation and Development (NCWCD) declared Harrat Al-Harrah as the first Protected Area in Saudi and established in 1987 (Seddon et al., 1997). Harrat Al-Harrah lies to the east of the Arabian Shield formation, in an area of ancient volcanic activity, a landscape dominated by numerous uplifted extinct volcanic cones and black basaltic boulders of the middle Miocene dating from 2 to 50 million years ago (Fig. 1a).

The protected area, extending about 13,775 km^2, mainly undulating desert steppes, volcanic rock mountain and some sabkhas, laying at about 850 m a.s.l., with Jabal Liss the highest point at about 1120 m. The reserve area comprises three major sectors, Liss, Tawqah and Ma'arik (Fig. 1). Hunting and grazing by domestic livestock other than camels is strictly prohibited in all these sectors. A fourth sector, the western Al-Qaidat, is also within a no-hunting zone, but is open for all forms of grazing and is not strictly patrolled. Other habitats in the reserve include broad vegetated wadis, smaller vegetated drainage lines, silty depressions, undulating gravel hills and steep sided hills (Jabals) (Seddon et al., 1997).

The weather in the reserve is generally very hot in the summer and cold winters. Frost can occur in the mid-winter and

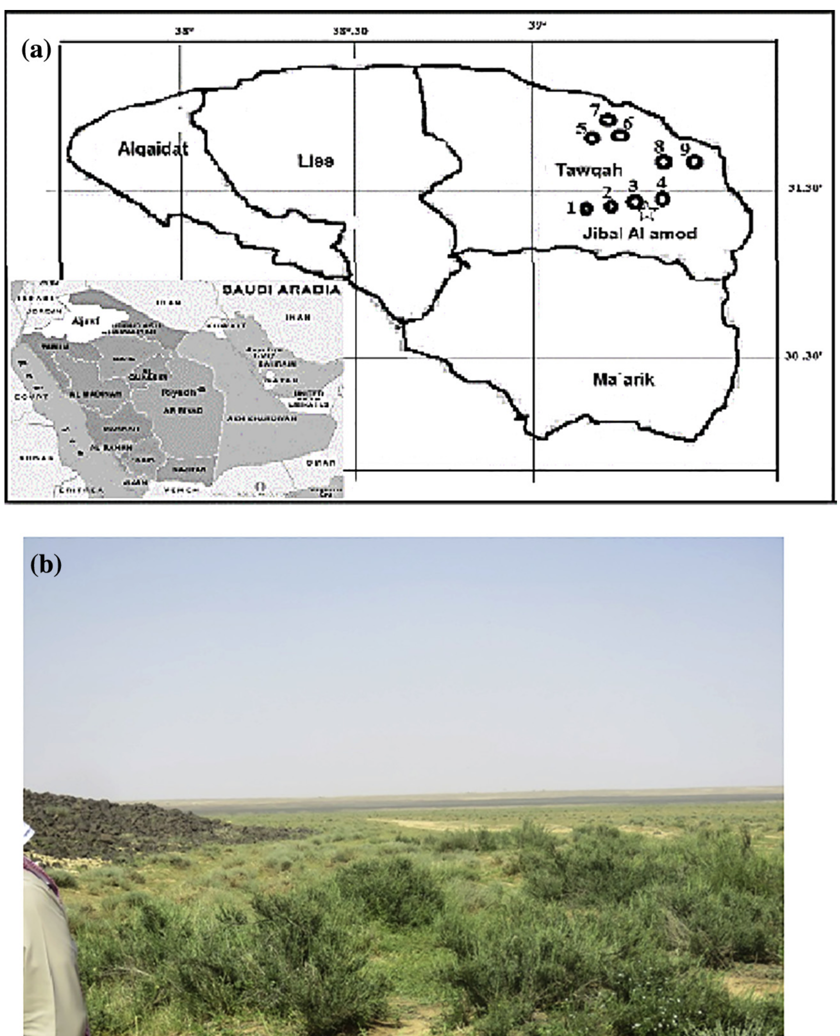

Fig. 1. Harrat Al-Harrah Protected Area showing the samples stands and location of the reserve in northern Saudi Arabia, and the principal geographic and administrative features (a). *Prunus arabica* habitat with associated species (authors photo) (b).

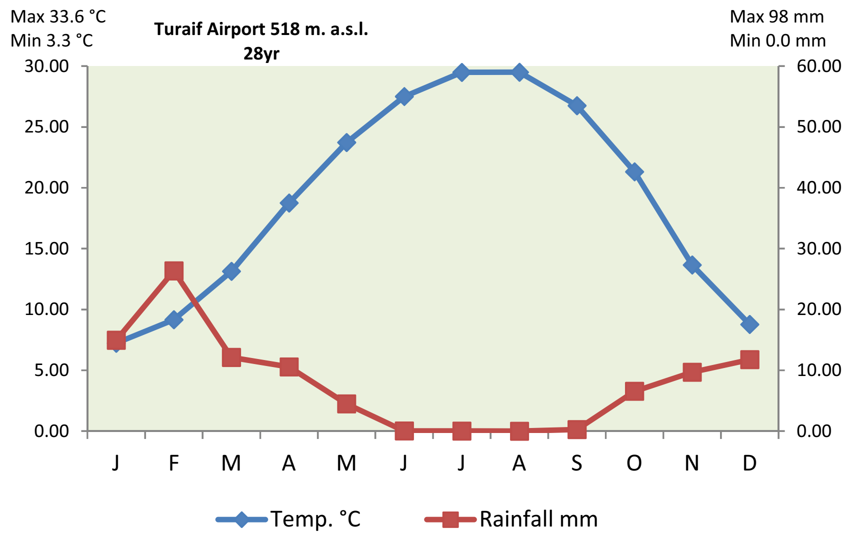

Fig. 2. Climate diagram for Turaif, Saudi Arabia (1987–2015).

temperatures may drop to below freezing. The average annual temperature is (20.1 °C). January is the coldest month with the lowest average temperature (7.1 °C), and the hottest month is August with the highest average temperature (33.6 °C) (Fig. 2). Precipitation is scanty and unpredictable. The average annual precipitation is 8.1 mm, which usually falls during the winter months; however, the inter-annual variability of rain is high, and extreme rainfall can be more than 100 mm.

2.2. Vegetation samples

A total of 9 sample stands were selected along the Harrat Al-Harrah reserve for study during the period from January 2015 to January 2016. Stands, measuring 50x50m, were selected to represent a wide range of physiographic and environmental variation in each wadi (Kent, 2012). The sampling process was carried out during the spring and autumn seasons when most species were expected to be growing (Fig. 1). The vegetation sampling involved listing of all plant species at the sample stands. The plant cover of each species was estimated as abundance values (Kent 2012; El-Sheikh et al., 2010). The plant specimens collected were identified according to Collenette (1999) and Chaudhary (1999–2001). Species life-forms were determined according to (Raunkiaer, 1934). A chronological analysis of the floristic categories of species was made to assign the recorded species to world geographical groups, according to Wickens (1978) and Zohary (1973).

2.3. Soil analysis of vegetation

Soil samples were collected from a depth of 0–50 cm at 3 random sites of each stand and mixed as a composite sample. The organic matter was determined based on loss on-ignition at 450 °C. Soil texture was determined by hydrometer method. Soil water extract was prepared (1:5), by dissolving 100 g air-dried soil in 500 ml distilled water for estimation of pH, electrical conductivity (EC) as mS cm^{-1} and soil nutrient elements (Ca, K, Na, Mg, Mn and Fe). P was determined using spectrophotometer (model ICP MSEOS 6000 Series). All procedures are outlined by Allen et al. (1989).

2.4. Vegetation data analysis

Species cover-type data matrices were done by creating two matrices – a matrix of nine sample stands × 82 common species cover values, and another matrix of nine sample stands × 82 species cover values and soil variables. Multivariate analyses were applied to both data sets for classification and ordination of the wadi vegetation. The first matrix was subjected for numerical classification using Two-way indicator species analysis (TWINSPAN) (Hill, 1979a) which concurrently classifies both stands and species directly by constructing an ordered 2-way table to exhibit the relationship between them in a clear manner. TWINSPAN produces a hierarchical classification of vegetation groups or plant communities and the plant communities were named after their dominant species. Detrended correspondence analysis (DCA) (Hill, 1979b) was applied to the first matrix data set in order to obtain an efficient graphical representation of the ecological structure of vegetation groups identified using TWINSPAN and to verify the identified vegetation units. Canonical Correspondence Analysis (CCA) (Ter Braak and Smilauer, 2002) was conducted with species cover, stands, and soil variables using the second matrix data set to identify correlations between derived vegetation associations and environmental data (El-Sheikh et al., 2010). For testing the relationships between the ordination axes and community and soil variables, Pearson's simple linear correlation coefficient (r) was used. Variation in species diversity indices (richness, evenness and dominance), sample plot traits, and soil variables in relation to plant community were assessed using one-way analysis of variance (SAS, 1989–1996).

3. Results

3.1. Floristic diversity

A total of 82 species belonging to 70 genera and 23 families were recorded from various sampled stands. The highly represented families were Compositae, Cruciferae, Poaceae, Caryophyllaceae and Fabaceae. Annual herbs constituted (83%) the largest floristic group, followed by perennials or subshrubs (13.41%) and shrubs (3.6%) (Table 1; Fig. 3a). Chronological analysis of the species in the study area revealed that monoregional elements belonging to the Saharo Arabian region have the highest share of species, representing 41.5% of the total species, followed by biregonal Saharo Arabian-Irano Turanian elements (17.1% species) and Mediterranean-Irano Turanian (11% species). The high value of pluriregional elements belonging to the Euro-Siberian-Mediterranean-Irano Turanian regions represent 6.1% of the total species (Fig. 3b).

Table 1
Synoptic table of recorded species in three vegetation clusters of the study area, after the application of TWINSPAN. The vegetation groups are: VGI: *Pulicaria undulata-Prunus arabica*, VGII: *Prunus arabica–Artemisia seiberi*, VGIII: *Artemisia seiberi-Achillea fragrantissima*. C: cover m 100 m^{-1}.

Species	Family	Life form	Chorotype	VGI			VGII				VGIII		C %	P %
				1	2	3	4	5	8	9	6	7		
Prunus arabica	Rosaceae	Shrub	SA-IT	44	2	28	11	35	14	8	8	8	17.56	100.0
Artemisia seiberi	Compositae	Perennial herb	SA	30	20	15	15	15	0	15	15	15	15.56	88.89
Erucaria hispanica	Cruciferae	Annual herb	Med	0	0	5	3	3	5	4	5	5	3.33	88.89
Medicago laciniata	Leguminosae	Annual herb	SA	2	0	4	0	5	0	4	5	5	2.78	77.78
Picris babylonica	Compositae	Annual herb	SA	1	4	2	5	5	0	0	5	5	3.00	77.78
Schismus barbatus	Gramineae	Annual herb	SA-IT	3	5	2	0	5	0	3	5	5	3.11	77.78
Trigonella stellata	Leguminosae	Annual herb	SA	2	3	2	5	3	0	0	5	5	2.78	77.78
Zilla spinosa	Cruciferae	Annual herb	SA	5	4	10	3	5	5	3	0	0	3.89	77.78
Achillea fragrantissima	Compositae	Perennial herb	Med.-IT	5	5	0	0	5	0	3	5	5	3.11	66.67
Erodium laciniatum	Geraniaceae	Annual herb	Med	2	3	2	0	0	0	3	5	5	2.22	66.67
Malva parviflora	Malvaceae	Annual herb	Med-IT	3	5	0	0	0	0	4	5	5	2.44	66.67
Paronychia arabica	Caryophyllaceae	Annual herb	SA	2	3	2	0	0	0	3	5	5	2.22	66.67
Stipa capensis	Gramineae	Annual herb	SA-IT	2	2	3	15	0	5	3	0	0	3.33	66.67
Bromus danthoniae	Gramineae	Annual herb	IT	2	0	2	5	5	0	2	0	0	1.78	55.56
Calendula arvensis	Compositae	Annual herb	Med-IT	0	0	4	0	5	0	3	5	5	2.44	55.56
Gastrocotyle hispida	Boraginaceae	Annual herb	SA-IT	2	0	0	3	0	0	3	3	3	1.56	55.56
Herniaria hirsuta	Caryophyllaceae	Annual herb	Med-Eu.sib-IT	0	0	0	2	2	0	1	2	2	1.00	55.56
Hordeum murinum	Gramineae	Annual herb	Med-IT	2	0	2	0	2	0	3	5	5	2.11	55.56
Phalaris minor	Gramineae	Annual herb	MED-IT	0	0	3	0	15	0	3	15	15	5.67	55.56
Plantago amplexicaulis	Planataginaceae	Annual herb	SA	1	0	2	3	3	0	3	0	0	1.33	55.56
Reseda alba	Resedaceae	Annual herb	SA	0	2	0	2	0	0	2	5	5	1.78	55.56
Anthemis sp.	Compositae	Annual herb	SA	0	0	2	4	0	0	0	2	2	1.11	44.44
Asteriscus heirochunticus	Compositae	Annual herb	SA	0	5	5	4	0	0	4	0	0	2.00	44.44
Avena barbatus	Gramineae	Annual herb	Med-Eu.Sib-IT	2	0	0	0	2	5	2	0	0	1.22	44.44
Brassica sp.	Cruciferae	Annual herb	SA	0	0	0	0	0	3	1	2	2	0.89	44.44
Heliotropium bacciferum	Boraginaceae	Perennial herb	SA-	3	3	3	3	0	0	0	0	0	1.33	44.44
Leysera lyseroides	Compositae	Annual herb	SA	2	0	0	4	5	0	3	0	0	1.56	44.44
Pulicaria undulata	Compositae	Perennial herb	SA-SM	30	30	70	40	0	0	0	0	0	18.89	44.44
Tribulus terrestris	Zygophyllaceae	Annual herb	Eu-Sib-Med-IT	4	3	3	0	2	0	0	0	0	1.33	44.44
Anthemis deserti	Compositae	Annual herb	SA	5	0	0	0	5	0	1	0	0	1.22	33.33
Arnebia decumbens	Boraginaceae	Annual herb	SA	0	2	0	0	2	0	1	0	0	0.56	33.33
Atriplex leucoclada	Chenopodiaceae	Shrub	SA	0	3	5	0	0	0	1	0	0	1.00	33.33
Malcolmia africana	Cruciferae	Annual herb	SA-Med	0	0	0	0	0	0	1	2	2	0.56	33.33
Notoceras bicorne	Cruciferae	Annual herb	SA	0	0	1	1	1	0	0	0	0	0.33	33.33
Papaver glaucum	Papaveraceae	Annual herb	Med-Eu.Sib-IT	0	2	0	0	0	0	0	2	2	0.67	33.33
Plantago ovata	Planataginaceae	Annual herb	SA-IT	1	2	2	0	0	0	0	0	0	0.56	33.33
Spergularia diandra	Caryophyllaceae	Annual herb	Med-IT-Eu.sib	0	2	0	0	0	0	0	5	5	1.33	33.33
Adonis dentata	Ranunculaceae	Annual herb	SA-IT	0	0	0	0	0	1	1	0	0	0.22	22.22
Arnebia hispidissima	Boraginaceae	Annual herb	SA	0	0	0	0	0	0	0	5	5	1.11	22.22
Astragalus crenatus	Leguminosae	Annual herb	SA	3	0	0	0	0	3	0	0	0	0.67	22.22
Astragalus schimperi	Leguminosae	Annual herb	SA	2	3	0	0	0	0	0	0	0	0.56	22.22
Brassica tournefortii	Cruciferae	Annual herb	SA-Med	0	0	0	0	0	0	0	2	2	0.44	22.22
Carrichtera annua	Cruciferae	Annual herb	SA	0	0	1	0	0	0	0	2	0	0.33	22.22
Leontodon laciniatus	Compositae	Annual herb	SA-IT	0	0	0	0	0	0	0	2	2	0.44	22.22
Plantago ciliata	Planataginaceae	Annual herb	SA	1	2	0	0	0	0	0	0	0	0.33	22.22
Pteranthus dichotomus	Caryophyllaceae	Annual herb	SA-IT	2	0	2	0	0	0	0	0	0	0.44	22.22
Reichardia tingitana	Compositae	Annual herb	Med-SA	1	0	1	0	0	0	0	0	0	0.22	22.22
Reseda decursiva	Resedaceae	Annual herb	SA	2	0	0	0	0	1	0	0	0	0.33	22.22
Scorzonera musillii	Compositae	Annual herb	IT	0	2	3	0	0	0	0	0	0	0.56	22.22
Sisymbrium irio	Cruciferae	Annual herb	Med-IT	0	0	0	0	0	0	0	3	3	0.67	22.22
Althaea ludwigii	Malvaceae	Annual herb	SA	0	0	2	0	0	0	0	0	0	0.22	11.11
Anisosciadium isosciadium	Umbelliferae	Annual herb	Med	0	0	0	2	0	0	0	0	0	0.22	11.11
Anvillea garcinii	Compositae	Perennial herb	SA	0	3	0	0	0	0	0	0	0	0.33	11.11
Astragalus tribuloides	Leguminosae	Annual herb	SA-IT	0	0	2	0	0	0	0	0	0	0.22	11.11
Atractylis mernephthae	Compositae	Annual herb	SA	0	0	0	2	0	0	0	0	0	0.22	11.11
Brandella erythraeae	Boraginaceae	Annual herb	SM	2	0	0	0	0	0	0	0	0	0.22	11.11
Bromus sp.	Gramineae	Annual herb	IT	0	0	0	0	2	0	0	0	0	0.22	11.11
Centaurea sp.	Compositae	Annual herb	SA	3	0	0	0	2	0	0	0	0	0.56	11.11
Cleome amblyocarpa	Capparaceae	Annual herb	SA-SM	3	0	0	0	0	0	0	0	0	0.33	11.11
Convolvulus pilosellifolius	Convolvulaceae	Perennial herb	IT	0	0	0	0	5	0	0	0	0	0.56	11.11
Cutandia memphitica	Gramineae	Annual herb	SA-IT	1	0	0	0	0	0	0	0	0	0.11	11.11
Ephedra sp.	Ephedraceae	Shrub	SA-SM	0	2	0	0	0	0	0	0	0	0.22	11.11
Filago desertorum	Compositae	Annual herb	SA-IT	0	0	2	0	0	0	0	0	0	0.22	11.11
Gypsophila capillaris	Caryophyllaceae	Annual herb	IT	0	2	0	0	0	0	0	0	0	0.22	11.11
Haloxylon salicornicum	Chenopodiaceae	Perennial herb	SA	0	0	0	0	2	0	0	0	0	0.22	11.11
Helianthemum lippii	Cistaceae	Perennial herb	SA-SM	0	2	0	0	0	0	0	0	0	0.22	11.11
Hypecoum pendulum	Papaveraceae	Annual herb	Med-IT	0	3	0	0	0	0	0	0	0	0.33	11.11
Isatis lusitanica	Cruciferae	Annual herb	Med-IT	0	0	0	0	0	1	0	0	0	0.11	11.11
Lappula spinocarpos	Boraginaceae	Annual herb	SA-IT	0	2	0	0	0	0	0	0	0	0.22	11.11
Launaea mucronata	Compositae	Annual herb	SA	2	0	0	0	0	0	0	0	0	0.22	11.11
Limonium lobatum	Plumbaginaceae	Perennial herb	SA	0	0	3	0	0	0	0	0	0	0.33	11.11
Orobanche cernua	Orobanchaceae	Annual herb	Med-SA-IT	2	0	0	0	0	0	0	0	0	0.22	11.11

Table 1 (*continued*)

Species	Family	Life form	Chorotype	VGI			VGII				VGIII		C %	P %
				1	2	3	4	5	8	9	6	7		
Plantago psammophila	Planataginaceae	Annual herb	SA	0	0	1	0	0	0	0	0	0	0.11	11.11
Polygonum palaestinum	Polygonaceae	Annual herb	Med	0	0	1	0	0	0	0	0	0	0.11	11.11
Rumex vesicarius	Polygonaceae	Annual herb	SA	0	0	0	2	0	0	0	0	0	0.22	11.11
Salsola lachnantha	Chenopodiaceae	Perennial herb	SA-IT	0	0	3	0	0	0	0	0	0	0.33	11.11
Schimpera arabica	Cruciferae	Annual herb	SA	1	3	0	0	0	0	0	0	0	0.44	11.11
Schismus arabiicus	Gramineae	Annual herb	SA	0	2	0	0	0	0	0	0	0	0.22	11.11
Silene sp.	Caryophyllaceae	Annual herb	Med	2	0	0	0	0	0	0	0	0	0.22	11.11
Sisymbrium erysimoides	Cruciferae	Annual herb	SA-Med	0	2	0	0	0	0	0	0	0	0.22	11.11
Teucrium polium	Labiatae	Perennial herb	Med-IT	0	0	4	0	0	0	0	0	0	0.44	11.11
Zoegea purpurea	Compositae	Annual herb	SA-IT	0	0	3	0	0	0	0	0	0	0.33	11.11

Chorotypes: EU-Sib = Euro-Siberian, SA = SaharoArabian, IT = Irano Turanian, Med = Mediterranean, SM = Somalia Masai.

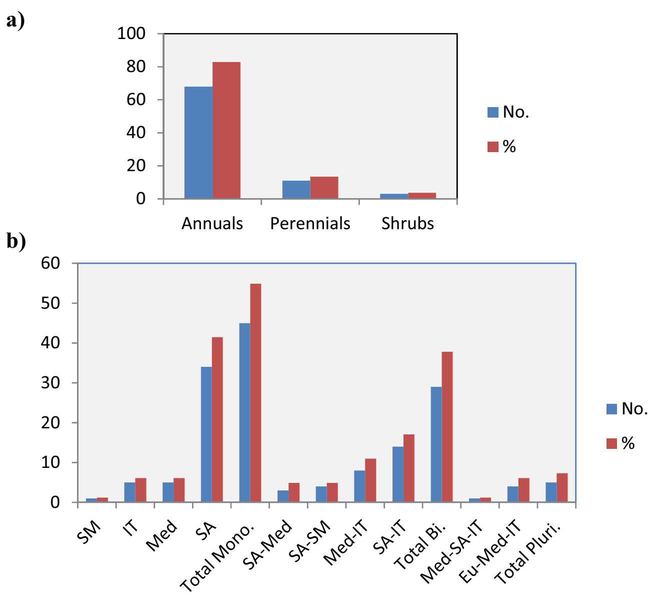

Fig. 3. Life form (a) and Chorotype (b) relative spectra of the recorded species in Harat Al-Harah (EU-Sib = Euro-Siberian, SA = SaharoArabian, IT = Irano Turanian, Med = Mediterranean, SM = Somalia Masai).

3.2. Plant associations

The application of TWINSPAN to the cover estimates of 82 selected species, recorded in Harat Alharah sample plots, indicated 3 vegetation groups separated at level 2, (i.e. plant communities) (Table 2; Fig. 4a,b). These 3 plant communities were characterized and named after the dominant and subdominant species as follows: VGI: *Pulicaria undulata-Prunus arabica*, VGII: *Prunus arabica–Artemisia seiberi*, VGIII: *Artemisia seiberi-Achillea fragrantissima*). The application of DCA confirmed the separation among these communities (Fig. 5b). CCA ordination was used to verify the correlation analysis between the environmental factors and CCA axes (Table 3; Fig. 5). Correlation analysis indicated that the separation of stands along the first axis is strongly affected positively by organic matter, evenness and Shannon and negatively by Mg, Ca, species cover and Simpson index (Table 3; Fig. 5a). On the other hand, the clay are correlated positively with the second axis, while the sand, Na, P, Fe, species number, species richness and Shannon index associated negatively with that axis. The distribution of annual herbs (e.g. *:Launaea mucronata, Stipa capensis, Tribulus terrestris, Anisosciadium isosciadium*) are located on the upper positive side of the axis 2 and associated soil factors: silt, EC, Simpson (Fig. 5b). Whereas, the perennial herbs (e.g. *Phalaris minor, Gypsophila capillaris, Anvillea garcinii, Pulicaria undulata*) are located on the lower negative side of the axis 2 with soil factors: sand, pH, species cover, species number, species richness, Ca, Mn, Mg, Fe, P.

3.3. Species diversity and soil relation

Species number is correlated positively with EC, Ca, Mn, Mg, Fe and P (r = 0.301, 0.99, 408, 0.349, 0.318 and 0.348 respectively) and negatively with organic matter (r = −0.754). Species richness is correlated positively with EC, Ca, Mn, Mg, Fe and P (r = 0.305, 0.430, 0.463, 0.300, 0.358 and 0.3955 respectively) and negatively with organic matter (r = −0.6805) (Table 4). Species cover exhibits positive correlation with pH, Ca and Mg (r = 0.391, 0.636 and 0.483 respectively) and negative with organic matter (r = −0.823). Evenness shows positive correlation with organic matter (r = 0.578) and K (r = 0.313) and negative correlation with Ca (−0.507) and Mg (r = −0.331). Simpson index is positively correlated with Ca (r = 0.526) and Mg (0.401) while negatively with organic matter (r = −0.458).

3.4. Soil characteristics of plant associations

The *Pulicaria undulata-Prunus arabica* community (VGI) had the highest values in pH, EC, silt, Na, Mg, P, K, Ca, Mn, Fe, species

Table 2
Presence (P) and cover (C) percentage of the characteristic species of three vegetation groups (VG) after the application of TWINSPAN technique.

VG	Stand No.	Stand %	Stand/habitat %	First dominant species	P	C	Second dominant species	P	C
I	(1, 2, 3)	33.33	Wadi 1 = 50 Wadi 2 = 50 Wadi 3 = 0	*Pulicaria undulata*	100	43.3	*Prunus Arabica*	100	24.66
II	(4, 5, 8, 9)	44.44	Wadi 1 = 0 Wadi 2 = 0 Wadi 3 = 100	*Prunus arabica*	100	16.7	*Artemisia seiberi*	75	11.25
II	(6, 7)	22.22	Wadi 1 = 0 Wadi 2 = 100 Wadi 3 = 0	*Artemisia seiberi*	100	15	*Achillea fragrantissima*	100	15

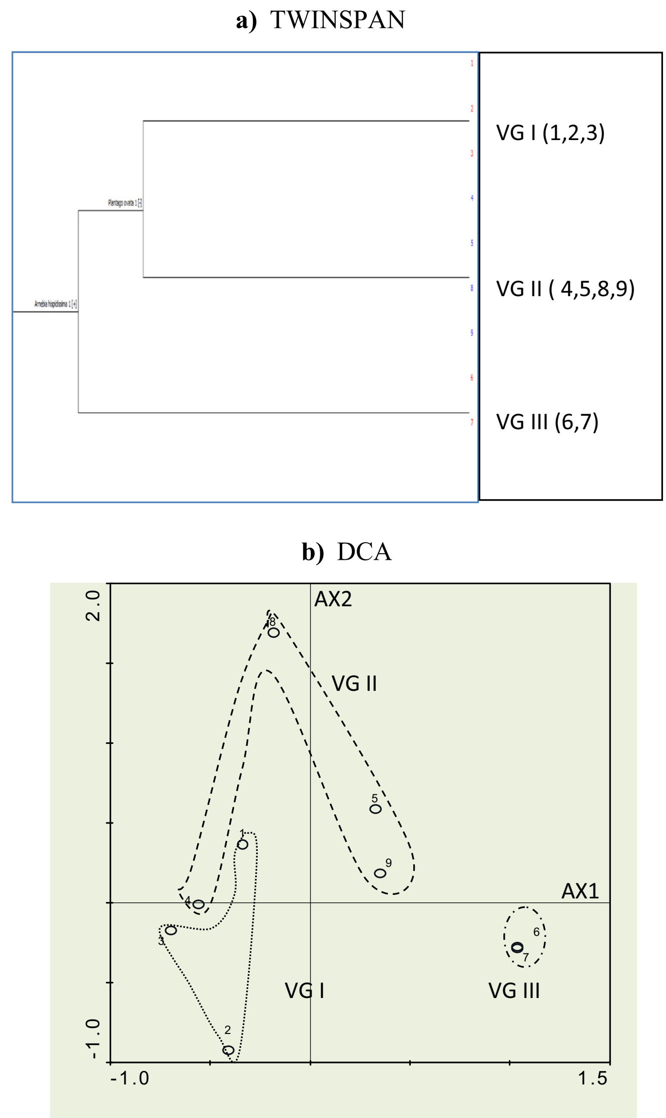

Fig. 4. Relationship between the three plant communities after the application of TWINSPAN (a) and DCA (b). VGI: *Pulicaria undulata-Prunus arabica*, VGII: *Prunus arabica–Artemisia seiberi*, VGIII: *Artemisia seiberi-Achillea fragrantissima.*

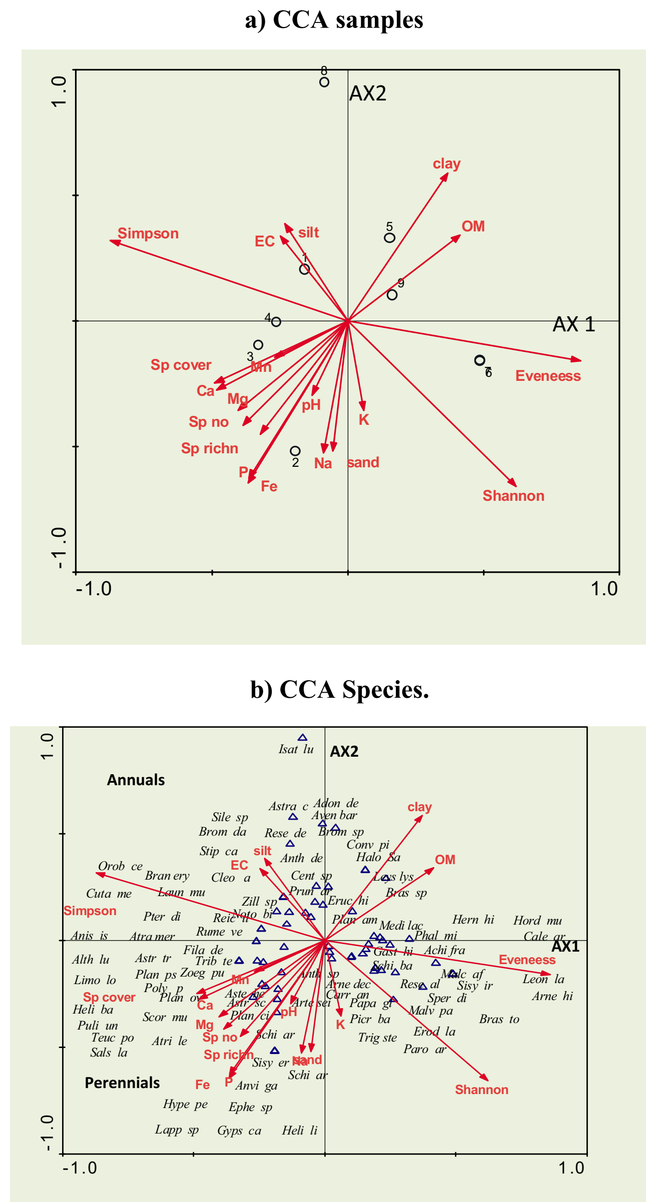

Fig. 5. CCA Biplot with environmental variables (arrows), the stands (a) and the abundant species represented by the first 4 letters of genus and species name (b). For complete names of species, see Table 1).

number, cover, richness, Simpson and lowest values in clay and species evenness (Table 5). The *Artemisia seiberi-Prunus arabica* community (VGII) had the higher values of organic matter, clay and lower values of pH, sand, Na, Ca, species number, cover, richness and Shannon. The *Artemisia seiberi-Achillea fragrantissima* community (VGIII) had the higher values of sand, evenness, Shannon and lower values of organic matter, EC, silt, Mg, P, K, Mn, Fe and Simpson index.

4. Discussion

P. arabica had a limited distribution in the north of Saudi Arabia and is restricted to few wadis of Harrat Al-Harrah. This might be due to the failure of regeneration by seeds as the flowers *of P. arabica* has been attacked by some unknown worms which feeds on the soft ovary with young ovules during the flowering stage itself. Therefore, the plants are propagated only vegetatively in the region.

In terms of floristic composition with *P. arabica*, the families Compositae, Cruciferae, Poaceae and Caryophyllacae had the highest representation in the study area, of which Compositae holds the status as the largest among the families in flora of Saudi Arabia (Migahid, 1990). These families are the most representative families in the northern sector of the Kingdom of Saudi Arabia resembling the typical Mediterranean-North African floristic structure which agrees with the results of Quezel (1978) and Al-Hassan (2006). A floristic analysis shows that the majority of plants in the study area are herbs (Therophytes) and subshrubs (Chamaephytes). The domination of chamaephytes on other life-forms seems to be a response to the hot dry climate and human interferences. Therophytes are adapted to dryness and limited rainfall prevailing in the region, and therefore spend their vegetative period in seed form (Asri, 2003). These results are congruent with the spectra of vegetation of the desert habitats in other parts of Saudi Arabia (El-Demerdash et al., 1995; Al-Turki and Al-Qlayan, 2003; Fahmy and Hassan, 2005; El-Ghanem et al., 2010; Alatar et al., 2012), and also reflect the vegetation spectra in other parts of

Table 3
Inter-set correlations of environmental variables in Harrat Al-Harrah with DCA axes.

No.	Variables	AX1	AX2	AX3	AX4
1	Organic matter %	0.4150*	0.3409	0.1557	0.2909
2	pH	−0.1304	−0.2950	−0.6289	0.0589
3	EC (mS/cm)	−0.2476	0.3376	0.7672	−0.2964
4	Sand %	−0.0548	−0.5198**	−0.6958	0.0859
5	Clay %	0.3700	0.5879**	0.4856	−0.0618
6	Silt %	−0.2306	0.3844	0.7796	−0.0947
7	Na ppm	−0.0897	−0.5270**	−0.3275	0.1640
8	Mg ppm	−0.4043*	−0.3571	−0.4435	0.0308
9	P ppm	−0.3646	−0.6274**	0.3033	0.2830
10	K ppm	0.0600	−0.3561	−0.2762	0.2462
11	Ca ppm	−0.4817*	−0.2755	−0.4585	−0.0247
12	Mn ppm	−0.2691	−0.1466	0.8310	−0.1054
13	Fe ppm	−0.3665	−0.6477**	0.3237	0.1013
14	Sp. number	−0.3859	−0.4158*	0.1471	−0.4922
15	Sp. cover (m–100 m^{-1})	−0.4897*	−0.2492	−0.2590	−0.5848
16	Sp. richnees (spp. $Stand^{-1}$)	−0.3219	−0.4500*	0.2353	−0.4504
17	Evenness	0.8585***	−0.1592	0.0983	0.3241
18	Shannon (Ĥ)	0.6207**	−0.6587**	0.1997	−0.2296
19	Simpson (C)	−0.8734***	0.3185	−0.2433	−0.0714

Significant level:
* $P \le 0.05$.
** $P \le 0.01$.
*** $P \le 0.001$.

Table 4
Pearson correlation (r) between species diversity and soil variables.

Soil variables	Sp. number	Sp. richness Spp./$stand^{-1}$	Sp. cover m/100 m^{-1}	Evenness	Shannon (Ĥ)	Simpson (C)
pH	0.1927	0.1327	0.3908*	−0.136	0.0171	0.2363
EC (mS/cm)	0.3010*	0.3054*	0.1361	−0.385*	−0.1915	0.2114
Bulk soil (%)						
Org. matter	−0.754***	−0.6805**	−0.8232***	0.5779**	−0.038	−0.458*
Sand	−0.058	−0.0965	0.1614	0.0557	0.1154	−0.004
Clay	−0.057	−0.0072	−0.2713	0.1657	0.0290	−0.214
Silt	0.1522	0.1738	−0.0413	−0.242	−0.225	0.1964
Soil minerals (ppm)						
Na	0.1420	0.1337	0.1753	0.0818	0.2241	0.0079
Ca	0.4995*	0.4305*	0.6357**	−0.507**	−0.1301	0.5258**
Mn	0.4082*	0.4629*	0.06630	−0.231	0.1173	−0.008
Mg	0.3491*	0.3000*	0.4827*	−0.331*	−0.059	0.4006*
K	−0.193	−0.1833	−0.1398	0.3131*	0.1669	−0.126
Fe	0.3185*	0.3582*	0.1146	−0.0472	0.2553	0.0173
P	0.3484*	0.3955*	0.0927	−0.056	0.2340	0.0289

Significant level:
* $P \le 0.05$.
** $P \le 0.01$.
*** $P \le 0.001$.

the Middle East (Danin and Orchan, 1990; Zahran and Willis, 1992; El-Bana and Al-Mathnani, 2009).

The high proportion of Saharo Arabian plants in the study area is because of the location of 'Harrat Al-Harrah' in the Saharo Arabian region. It may also be stated that the Saharo Arabian species which are restricted in their distribution to the central strip of Saudi Arabia are more abundant in habitats of more favorable micro-environmental conditions and those providing better protection (Zohary, 1973; Ghazanfar and Fisher, 1998; Hegazy et al., 1998; El-Ghanem et al., 2010). The high attained of many bi and multiregional elements in Harrat Al-Harrah (60%), may be the studied area was widely regarded as a transition zone between the floristic regions of Mediterranean, Irano-Turanian and Euro-Siberian elements. The influences of these phytogeographical zones were very much reflected in the flora of Northern region of Saudi and reflecting their differential capability to penetrate the region (Alatar et al., 2012).

There are three vegetation groups associated with the distribution of *P. arabica*: two of them are characterized by *P. arabica* in the study area. Similar of these plant communities and specially community of *P. arabia* were described by El-Sheikh and Chaudhary (1988) in their study on the Harrat Al-Harrah vegetation. Hence, it is interesting to report that *P. arabica* still remain as the main plant community component in the study area and also to find out why *P. arabica* is present in some areas of these wadis and not in others. The amount and duration of the water flow through the wadi could be one of the determining factors (El-Sheikh and Chaudhary, 1988). Moreover, the *Pulicaria undulata-Prunus arabica* community (VGI) inhabits wider on loamy deeper soils of wadi-1 and wadi-2, which have the alkaline silty soil habitat with high content of minerals. These wadis are characterized by high species diversity, cover and richness. This increase in the rate of plant colonization in patches was probably caused by nutrient enrichment, very deep loose soil particles, easily penetrable (more permeable soil) and without stones i.e. good soil conditions of aeration with unlimited influx of seeds of associated species. Most of the associated plant species were found within or at the phytogenic edges of the *P. arabica* patches, indicating that the seeds were, to a large

Table 5
Mean ± standard deviation of soil variable and diversity indices of 3 vegetation groups. **Max. and min. are in bold.**

VG	VG 1	VG 2	VG 3	F-Value	P-Value
pH	**8.13** ± 0.15	**8.10** ± 0.00	8.13 ± 0.06	0.175	0.843
EC (mS/cm)	**0.20** ± 0.10	0.15 ± 0.06	**0.11** ± 0.02	1.281	0.336
Bulk soil %					
Org. matter	1.57 ± 0.32	**2.13** ± 0.15	**1.94** ± 0.12	6.221*	0.028
Sand	86.00 ± 2.00	**85.50** ± 5.00	**87.33** ± 2.31	0.222	0.807
Clay	**4.67** ± 1.15	**5.50** ± 2.52	5.33 ± 1.15	0.182	0.837
Silt	**9.33** ± 1.15	9.00 ± 2.58	**7.33** ± 1.15	0.976	0.423
Soil minerals (ppm)					
Na	**111.87** ± 24.77	**83.45** ± 5.51	92.54 ± 16.85	2.606	0.143
Mg	**1530.97** ± 944.76	744.43 ± 43.00	**735.68** ± 64.89	2.552	0.147
P	**135.17** ± 54.57	63.15 ± 23.45	**51.01** ± 30.82	4.704*	0.051
K	**434.97** ± 36.13	363.30 ± 46.63	**358.28** ± 17.08	4.138	0.065
Ca	**144.33** ± 90.34	**56.65** ± 7.62	59.30 ± 10.22	3.298	0.098
Mn	**28.63** ± 11.93	9.25 ± 1.76	**6.39** ± 0.88	10.733**	0.007
Fe	**118.53** ± 42.07	63.58 ± 10.75	**54.82** ± 5.70	6.529*	0.025
Species diversity indices					
Sp. number	**36.67** ± 2.31	**22.00** ± 7.87	27.33 ± 0.58	6.574*	0.025
Sp. cover (m/100 m^{-1})	**177.67** ± 35.30	**108.00** ± 43.64	135.33 ± 0.58	3.554	0.086
Sp. richness (spp./$stand^{-1}$)	**6.90** ± 0.21	**4.49** ± 1.50	5.37 ± 0.11	5.098*	0.043
Evenness	**0.80** ± 0.06	0.88 ± 0.04	**0.95** ± 0.00	9.248**	0.011
Shannon (Ĥ)	1.25 ± 0.08	**1.15** ± 0.18	**1.36** ± 0.01	2.359	0.165
Simpson (C)	**0.11** ± 0.03	0.10 ± 0.04	**0.05** ± 0.00	4.136	0.065

Significant level:
* $P \leq 0.05$.
** $P \leq 0.01$.

extent, dispersed by wind to the wadi bed and trapped by *P. arabica* phytogenic hillocks (Magnusson et al. 2014). On the other hand, *Artemisia seiberi-Prunus arabica* community (VGII) inhabits of wadi-3, are characterized by the decrease in the rate of plant colonization or species-poor of low diversity probably caused by the small wadi and relatively high in clay, lower content of sand and nutrient contents i.e., poor compacted soil condition. In this community, most of the associated species are found on the edge of *P. arabica* phytogenic, this occurrence at the margins suggested that the competition from established plants inhabit establishment of new arrivals (El-Sheikh, 2005; Magnusson et al. 2014).

The correlation analysis indicates that the species diversity (e.g. species number and richness) is positively correlated with minerals (e.g. EC, Ca, Mn, Mg and Fe). These factors may reflect the degree of wadi bed maturation with presence of fine sediments of volcanic rocks in the study area and mature stages in plant succession on these wadi beds (Kassas and Imam, 1954; El-Sheikh 2005; Alatar et al., 2012). On the other hand, low of species diversity on poor compacted soil which had increasing of clay and organic matter. Similar correlations were reported by (El-Demerdash et al. 1995; Abbadi and El-Sheikh 2002; El-Sheikh et al. 2006, 2010).

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