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RESEARCH ARTICLE

Phenotypic diversity of *Medicago* crop wild relatives growing in Lebanon

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Abstract *Medicago* L. (Fabaceae; Papillionoidae) has high nutritive value, palatability, and ability to improve the soil fertility which puts it as one of the world's most important forages. *Medicago* genetic resources are suffering from anthropogenic destructions, overgrazing, climate change and drought. Using the results of a previous gap analysis, which prioritized the species and sites for in situ and ex situ conservation, this study aims to undertake ex situ conservation activities for high priority annual Lebanese species. Accessions of the target species were collected, multiplied, characterized and conserved at Genebank of The International Center for Agricultural Research in the Dry Areas (ICARDA). Based on characterization data, morphological diversity assessment is carried out to analyse the phenotypic variability pattern in relation with the environmental conditions of the collection sites. The analysis of 26 characters applied on 19 collected species has shown a significant variability for 13 characters. The species Medicago polymorpha L. from Chwaifat, M. polymorpha from Shebenieh, M. truncatula Gaertn and M. orbicularis (L.) Bartal from Jeita, and M. constricta Durieu from Bwerij had characters that could be related to drought tolerance as they have displayed a high early vigour and an early flowering. In depth analysis of the characters early vigour, days to flowering and days to pod formation within the species in relation to drought tolerance further informed our proposed management plan. On this basis, the accessions showing a high adaptability to harsh conditions will be subject to in situ conservation.

Keywords Conservation · Crop wild relatives · Distribution · *Medicago* · Morphological diversity

Nisrine Karam and Zeina Choueiry have been equally contributed to this work.

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Introduction

The genus *Medicago* L., member of the family Fabaceae and subfamily Papilionoideae is commonly known as "medic" or "burr clover" (Kenicer 2005). The genus includes ca. 85 species and 18 infraspecies taxa (Small and Jomphe 1989). Of these species, two are shrubs, 20 are herbaceous perennials and 63 are herbaceous annuals (Maxted and Bennett 2001).

The genus is native to the Fertile Crescent, including Turkey, Iraq and Iran, and to South Caucasus and the Eastern Mediterranean basin. Annual medics were introduced to America and Australia through human migration only from the seventeenth century (Maxted and Bennett 2001). It is grown in a wide range of environments from Arabian deserts to the subtropics of Australia and through the cold temperate regions of Europe, west and central Asia, and South and North America (Prosperi et al. 2001). The genus is mainly distinguished by its pods and compound stipules (Rahman and Ismot Ara Parvin 2014). The growth habit of *Medicago* is widely influenced by the growing conditions, it varies from prostrate to upright. The leaves are digitately trifoliate, their shape varies according to the species. In general, the upper sides are less hairy than the lower sides and when the plant becomes older, the plant may lose its trichomes and become glabrous (Al-Atawneh et al. 2009).

Medicago plants are best suited to neutral and alkaline soils (Skinner et al. 1999; De Varennes et al. 2001). The plant characteristics are affected by soil type and salinity (Piano and Francis 1992; Bounjemate et al. 1992), and by climatic factors such as altitude and annual rainfall (Ehrman and Cocks 1990; Piano et al. 1991). Generally, annual species are found in open, dry and disturbed areas while the perennials are observed in moist, closed communities (Al-Atawneh et al. 2009). The hard seed coat of *Medicago* plays a pivotal role in the dispersal and the viability of the species. *Medicago* is characterized by its high nutritive value due to its high potential of preventing ruminant bloating (Marten et al. 1987), its palatability and its ability to improve the soil fertility (Basbag et al. 2009; Khaef et al. 2011).

Around 42,000 accessions of *Medicago* are retained in three main gene banks: the Australian *Medicago* Genetic Resources Center (AMGRC), the United States Department of Agriculture (USDA) and the International Centre for Agricultural Research in the Dry Areas (ICARDA) (Maxted and Bennett 2001). There is currently no provision for long term in situ conservation of the *Medicago* germplasm and some gaps in ex situ collections. Despite the efforts done, some species are poorly represented, and some are highly threatened and are subjected to extinction due to several factors. *Medicago*, as the case of many crop wild relatives, is suffering from continuous depletion in population size through overexploitation, habitat destruction and overgrazing (Al-Atawneh et al. 2009).

Conservation initiatives whether through in situ conservation or ex situ conservation, become important to halt the irreversible loss of genetic resources and enhance the sustainability of crop diversity. A successful conservation strategy of the genetic diversity starts with an eco-geographical survey based on background information followed by germplasm collection (Padulosi et al. 2011). The morphological characterization, based on quantitative and qualitative characters, may give insight into the diversity of the studied species. The presence of specific characters allows the concerned species to overcome specific challenges in order to be included in future breeding programs and restoration efforts.

In Lebanon, 37 species of *Medicago* are present according to literature (Post 1932; Mouterde 1986; Tohme and Tohme 2014; Al-Atawneh et al. 2009). A previous study constructed a database from literature and online websites to apply gap analysis and elaborate richness and distribution maps in order to indicate the priority species for collection and priority areas for survey or for in situ conservation (Al-Beyrouthy et al. 2019). Accordingly, the findings have been the baseline of this study. The present study aims at: germplasm collection, morphological characterization and identification of priority species for in situ conservation or for reintroduction in dry areas according to target characters. This study will also contribute in the detection of drought tolerant species according to their phenotypic plasticity and priority species for in situ restoration will be highlighted.

Material and methods

Plant material

Thirty-six (36) sites distributed in northern Lebanon, along the coast, and in the internal regions of the country were visited during August 2016. The selection of sites was done according to priority species identified from previous gap analysis (Al-Beyrouthy et al. 2019); GPS location and elevation were recorded for each site. During this period, fully mature seeds were collected. The distance between two sites (in the same region) was at least 5 km; this allowed to collect appropriate data on distribution, habitat and the distance between populations. The identification of *Medicago* species was done on site based on (Al-Atawneh et al. 2009) then confirmed at the laboratory. Accession collected (Supplementary Table S1) were planted in November 2016-August 2017 intended for multiplication and morphological characterisation.

Morphological descriptors

A total of 26 morphological characteristics were considered. The observed qualitative characters included growth habit, leaflet shape, leaflet margin, leaflet pubescence, pubescence position, leaflet marker shape, stipule shape, pod spinescence, spine hardiness, seed shape, seed colour, and early vigour. The recorded characters and their given evaluations are listed in Table 1. Quantitative characters included days to first flowering, days to 50% flowering, plant height (cm), days to podding, days to maturity, peduncle length (cm), petiole length (cm), number of flowers per inflorescence, number of pods per inflorescence, seed characterisation and grain yield (Table 2).

Statistical analysis

The open access software DIVA-GIS V. 7.1.7 (Hijmans et al. 2005) was used to create distribution maps and obtain annual precipitation for each site. The experimental and eco-geographical data were processed using 2015.

Table 1 Medicago accessions qualitative characteristics

Observed characters	Description
Growth habit	(1) Prostrate, (2) semi-prostrate, (3) semi-erect, (4) erect
Leaflet shape	(1) Cuneate, (2) lanceolate, (3) obcordate, (4) oblanceolate, (5) obovate, (6) orbicular, (7) oval, (8) ovate, (9) rhomboid
Leaflet margin	(1) Entire, (2) toothed, (3) serrate, (4) incised, (5) lobed
Leaflet pubescence	Present or absent
Pubescence position	(1) On the upper surface, (2) lower surface, (3) both surfaces, (4) leaf margin only
Marker shape	(1) Plain, (2) blotch, (3) dot, (4) fleck, (5) broken crescent, (6) ellipse, (7) blotch and flecked crescent
Stipule shape	(1) Hastate, (2) semi-hastate, (3) semi-sagittate, (4) sagittate
Pod spinescence	(1) Spineless, (2) short spines and 90°, (3) long spines and 90° to 180°, (4) long spines and 180°, (5) short spines and 180°, (6) short and 90° to 180°
Pod hardiness	(1) Smooth spines, (2) intermediate spine hardiness, (3) hard spines
Seed shape	(1) Reniform, (2) sub-reniform, (3) deltoid, (4) verrucose
Seed colour	Yellow, brown, light brown, dark brown, green and black
Early vigour	(3) Poor, (5) intermediate, (7) high, (9) very high

Table 2 Medicago accessions quantitative characteristics

Observed characters	Description
Days to first flowering	Three flowers from three individual plants in the same accession have blossomed
Days to 50% flowering	50% of the flowers, in the same accession, have blossomed
Plant height (cm)	The tallest plant of each accession was measured after vegetative growth cease
Days to podding	After the formation of pods of the first nine flowers
Days to maturity	The plot was considered to be at its maturity stage when 80% of the plot was mature
Peduncle length (cm)	This trait was measured using a ruler at full flowering
Petiole length (cm)	The petiole length was measured visually using a ruler
Flowers per inflorescence	Three random inflorescences from three different plants per accession
Pods per inflorescence	After podding, three random inflorescences from three different plants per accession
Seed characterization	Pod length and width and spines length measured using a ruler

Statistical analysis of the qualitative characters was also carried out using Microsoft Excel. The quantitative characters were analysed using SPSS software, version 21. Correlations were carried out using five quantitative characters, two qualitative characters and 3 eco-geographical factors using the SPSS package. The principal component analysis (PCA) was done using R Data Analysis software.

Results

Collection sites

The distribution of collection sites is shown in Fig. 1. The elevation of the sites ranges from sea level as in Damour and Jieh up to 1588 m in Tarchich. Nine (9) regions have low elevation (less than 500 m), four (4) regions fall between 500 and 1000 m, and the remaining regions (23) are located above 1000 m. The mean annual rainfall followed the same pattern as altitude, as it increases with the increase in elevation; with few exceptions in Bekaa valley and the Eastern facing slopes of Mount Lebanon.

Species and accessions in the collection sites

The number of species per site varied from one species in Tarchich and Falougha to seven species in Kousba, Ain Zebde and Shebenieh (Fig. 1). During the collection, Medicago polymorpha L., M. minima (L.) Bartal, Medicago orbicularis and M. praecox (L.) Bartal were found abundantly so a high diversity was observed in those species.

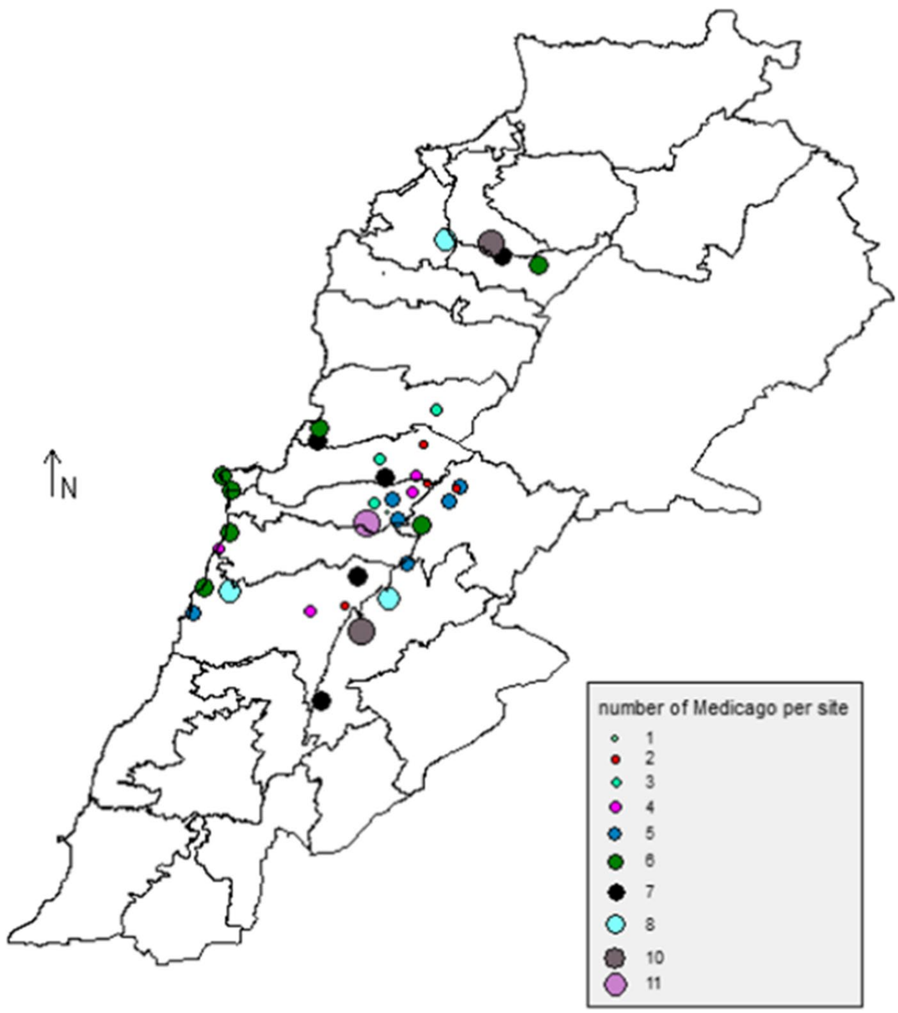

Fig. 1 Number of Medicago species collected from each site

A total of 19 species (Fig. 2) were identified over all the studied sites for a total of 168 accessions (out of 197 collected): *Medicago blancheanna* Boiss., *M. constricta* Durieu, *M. coronata* (L.) Bartal., *M. doliata* Carmign., *M. rigidula* (L.) All., *M. radiata* L., *M. granadensis* Willd., *M. intertexta* (L.) Mill., *M. lupulina* L., *M. monspeliaca* L., *M. rotata* Boiss., *M. rugosa* Desr., *M. scutellata* (L.) Mill., *M. truncatula* Gaertn., *M. turbinata* (L.) All., *M. minima* (L.) Bartal L., *M polymorpha* L., *M. praecox* DC., *M. orbicularis* (L.) Bartal. The most common species found in 20 sites and more were: *M. polymorpha* L.,

Fig. 2 Morphological visualization for the pods of the collected species and the genus flower shape **a** *Medicago blancheanna* Boiss., **b** *Medicago constricta* Durieu, **c** *Medicago coronata* (L.) Bartal., **d** *Medicago doliata* Carmign., **e** *Medicago* granadensis Willd., **f** *Medicago intertexta ciliaris* (L.) All., **g** *Medicago lupulina* L., **h** *Medicago minima* (L.) L., **i** *Medicago monspeliaca* (L.) Trautv., **j** *Medicago orbicularis* (L.) Bartal., **k** *Medicago polymorpha* L., **l** *Medicago praecox* DC., **m** *Medicago radiata* L., **n** *Medicago rigidula* (L.) All., **o** *Medicago rotata* Boiss., **p** *Medicago rugosa* Desr., **q** *Medicago scutellata* (L.) Mill., **r** *Medicago truncatula* Gaertn., **s** *Medicago turbinata* (L.) All., **t** flower shape of the genus

M. orbicularis (L.) Bartal., M. minima (L.) Bartal L., *M. praecox* DC. On the other hand, other species were present in one site only: *M. blancheanna* Boiss., *M. intertexta* (L.) Mill. and *M. lupulina* L.; or in two sites *M. radiata* L., *M. granadensis* Willd. and *M. truncatula* Gaertn.

Characterization

Morphological descriptors

The analysis of mean, standard deviation and coefficient of variation for the quantitative and qualitative characters shows a high variation in *Medicago* species (Table 3). The coefficient of variation varied from 10 to 100%. The characters with low variability included the stipule shape (13%), days to flowering and days to 50% flowering (11%), days to podding and days to maturity (10%) and the pubescence position (10%). The highest variability was observed for number of pods per inflorescence (100%), the seed weight (99%) and the number of flowers per inflorescence (98%). The highest variability in qualitative morphological traits was observed in growth habit (Fig. 3a), leaflet shape (Fig. 3b), pod spinescence (Fig. 3c) and seed colour (Fig. 3d). Thirty-six percent had a prostrate growth habit, and 36% had a semi prostrate growth habit. Most of the accessions, about 35% had a lanceolate leaflet shape. Long spines with an angle of insertion between 90 and 180° were observed in 42% of the accessions and spineless accessions counted for 25%. The majority of the accessions, 46%, had yellow seeds while 4% had black seeds. The highest variability in the quantitative morphological traits was observed in 100 pod weight (Fig. 3e), number of flowers per inflorescence (Fig. 3f), seed weight (Fig. 3g) and number of pods per inflorescence (Fig. 3h). The weight of 100 pods ranged between 0.22 and 43.35 g. Twelve percent of the accessions had 100 pod weight less than 1.96 g; similarly, 12% had 100 pod weight above than 17 g and 76% had 100 pod weight between 1.96 and 17 g. Only 7% had more than seven flowers per inflorescence, whereas 93% had less than seven flowers per inflorescence. The grain yield ranged between 0.1 and 66.70 g. One percent of the accessions had a low grain yield, less than 0.1 g, 14% had a high grain yield, above than 17.11 g, and 85% had a grain yield between 0.1 g and 17.11 g. Only 7% had more than six pods per inflorescence, whereas 93% had less than six pods per inflorescence.

Table 3 Mean, standard deviation and coefficient of variation of the quantitative and qualitative characters of Medicago accessions

Characters	Mean	Standard deviation	Coefficient of variation (%)
Growth habit	1.9	0.85	44
Leaflet shape	4.17	2.8	67
Leaflet margin	3.2	1.2	37
Leaflet pubescence	1.5	0.50	33
Pubescence position	3	0.3	10
Marker shape	3.18	1.26	39
Stipule shape	2	0.26	13
Pod spinescence	3.16	1.65	52
Spine hardiness	2.28	0.76	33
Seed shape	2.14	0.63	29
Seed colour	2.13	1.5	70
Early vigour	4.7	1.7	36
Days to flowering	94.95	11.28	11
Days to 50% flowering	100.39	11.18	11
Plant height (cm)	43.50	15.04	34
Days to podding	101.58	10.80	10
Days to maturity	174.15	17.33	10
Length of the peduncle (cm)	1.15	0.84	73
Flowers per inflorescence	3.40	3.35	98
Pods per inflorescence	2.76	3.11	100
Pod height (cm)	0.65	0.34	52
Pod width (cm)	0.79	0.48	60
Spine length (cm)	0.18	0.13	72
100 Seed weight (g)	0.51	0.31	60
100 Pod weight (g)	9.48	7.52	79
Seed weight (g)	8.60	8.51	99

Species characterization

Among the 26 characters, an in depth characterization within species was done for three characters related to drought tolerance, namely early vigour, flowering and podding. The categories were assigned based on the normal distribution as follow: for early vigour, score 3 corresponds to a poor vigour, 5 to intermediate early vigour, 7 to vigorous

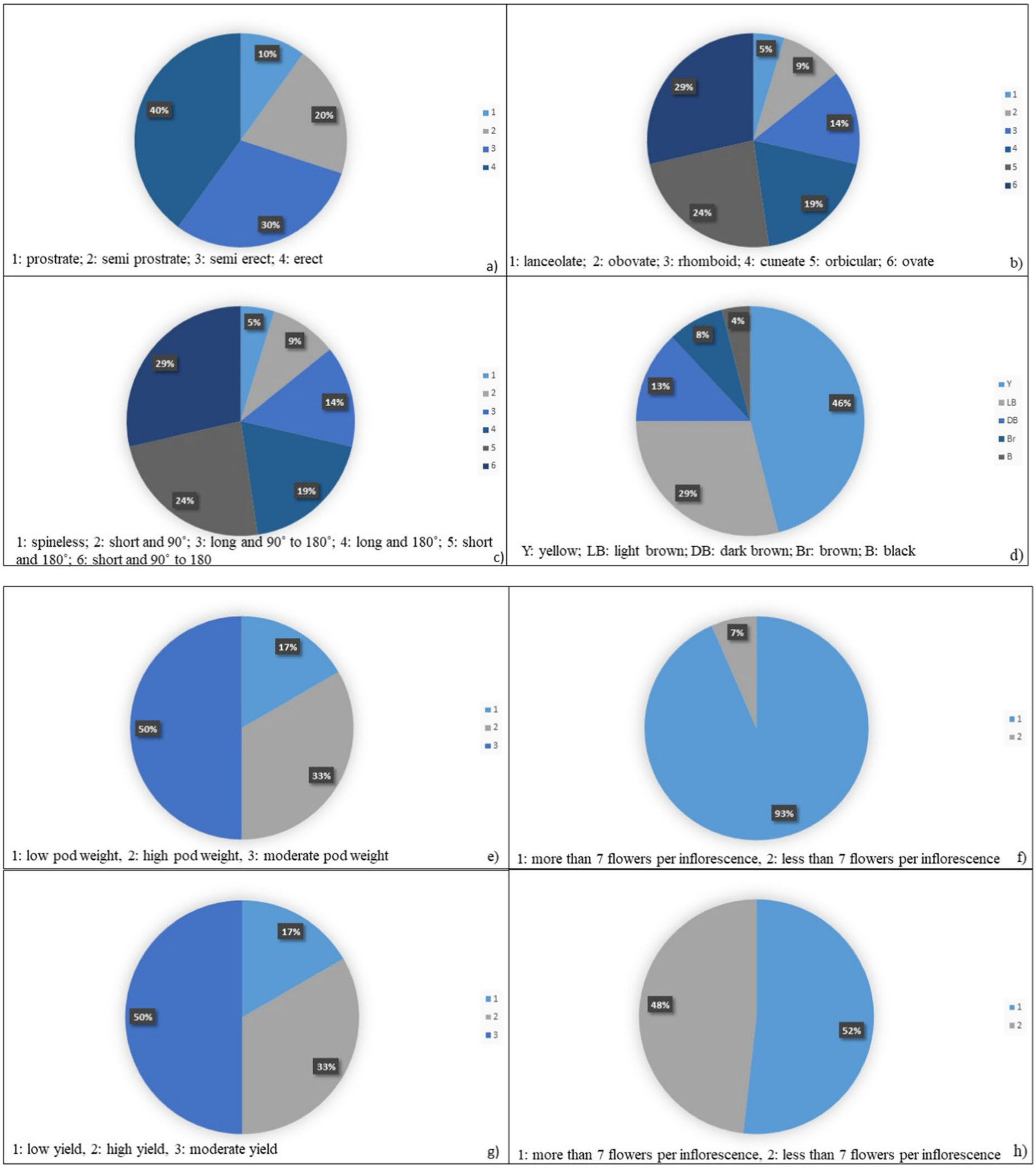

Fig. 3 **a** Growth habit, **b** leaflet shape, **c** Pod spinescence, **d** Seed colour, **e** 100 pod weight, **f** Number of flowers per inflorescence, **g** Grain yield, **h** Number of pods per inflorescence

plants and 9 to very vigorous ones. Early flowering is considered from day 69 till day 83, while late flowering is considered from day 106 till day 134. Pod formation was considered early when it occurred within seven days from flowering, whereas it is considered to be late when it occurred more than seven days after flowering.

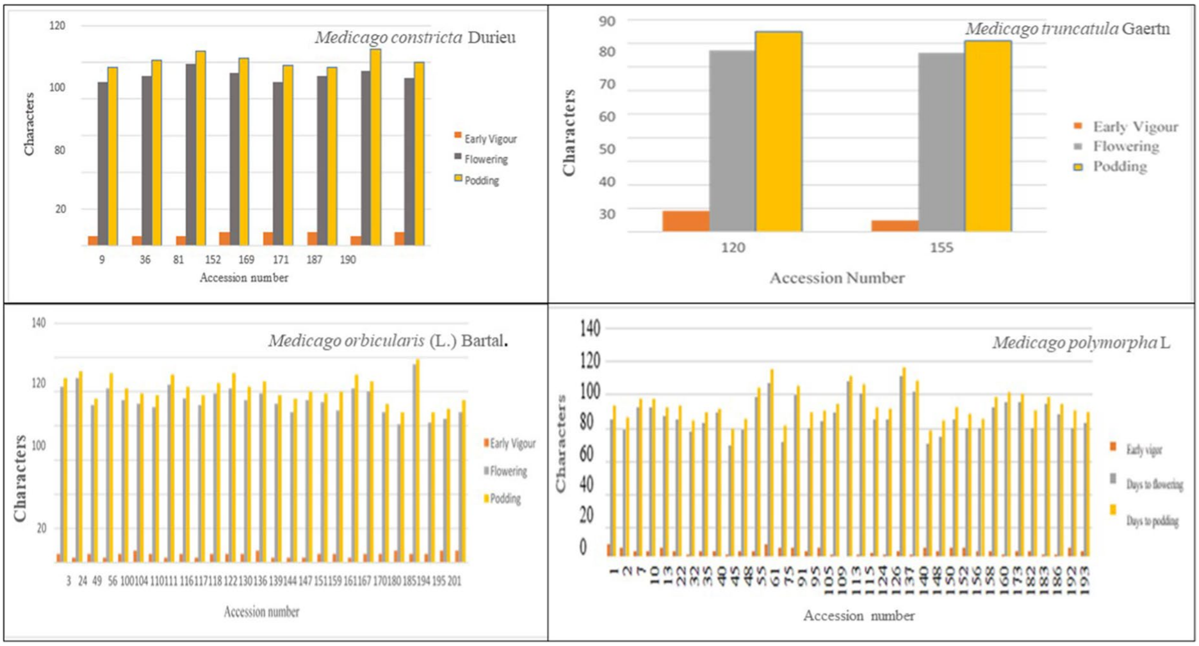

Fig. 4 The early vigour, the flowering and the podding of *Medicago constricta* Durieu, *Medicago truncatula* Gaertn, *Medicago orbicularis* (L.) Bartal. and *Medicago polymorpha* L

Medicago constricta

Medicago constricta was represented by eight accessions (Fig. 4). Early vigour was high in four accessions and medium for the remaining accessions.

Only one accession showed early flowering at day 81. Flowering date of the remaining seven accessions ranged from day 89 to day 99. On the other hand, only one accession displayed early pod formation as it took place six days after flowering. The remaining accessions had a delayed podding date, especially accession 190 where the podding took place 20 days after flowering.

Medicago truncatula

Medicago truncatula was represented by two accessions (Fig. 4). Accession 120 displayed very high early vigour while the accession 155 had medium early vigour. Both accessions had aproximately the same early flowering date (77 and 76 respecively). Conversely, the accession 155 had an early pod formation (six days after flowering) while accession 120 had late pod formation (nine days after flowering).

Medicago orbicularis

Medicago orbicularis was represented by 27 accessions (Fig. 4). Five accessions had high early vigour. Medium early vigour was observed in 14 accessions, and 8 accessions had low early vigour. The flowering date ranged from day 81 to day 116 where two accessions (180 and 194) had early flowering before day 83. Similarly, two accessions (24 and 185) had late flowering after day 106. Concerning pod formation, eight accessions displayed early pod formation. The most retarded pod formation took place in accession 159 at 12 days after flowering.

Medicago polymorpha

Medicago polymorpha was represented by 36 accessions (Fig. 4). Two accessions (1 and 61) had very high vigour, nine accessions had high vigour, 15 accessions had medium early vigour and 10 accessions had low early vigour. Flowering extended between day 69 till day 111. Fourteen accessions had early flowering before day 83, whereas 3 accessions had late flowering after day 106. Concerning pod formation, it took place early in eight accessions (less than 7 days after flowering), whereas 17 accessions had late pod formation (more than 7 days after flowering), and the remaining 11 accessions set pods 7 days after flowering.

Correlation analysis between morphological characters and ecogeographical factors

The highest and significant correlation (Table 4), was observed between days to flowering and days to podding (0.981) followed by the correlation between 100 seed weight and 100 pod weight (0.743). Conversely, significant negative correlation was observed between the early vigour and days to flowering (− 0.345), followed by the correlation between days to flowering and 100 seed weight (− 0.326). The highest correlation was observed between the altitude and the precipitation (0.801) followed by the correlation between days to flowering and the altitude (0.534). Conversely, a significant negative correlation existed between the altitude and the temperature (− 0.697), and between the precipitation and the temperature (− 0.674) (Table 4).

Section on priority sites

After studying the diversity present within and between species and after identifying characters that could be used as indicators for drought tolerance traits, priority sites and species for ex situ and in situ conservation were identified. This list of priority species was obtained by combining the two gaps of in situ and ex situ conservation. The results show that eight species are the most important and they are considered as rare. These species are: *M. arabica, M. astroites, M. granadensis, M. hypogea, M. laciniata, M. murex, M. orthoceras* and *M. tenoreana*. Our results corroborate those obtained by Al-Beyrouthy et al. 2019 (In press). This latter study shows the most important sites where these eight species could be found.

Discussion

Characters used as drought tolerance indicators are early vigour and early flowering. Early vigour limits water loss caused by direct evaporation from soil surface. In the case of significant early vigour, leaves store water for a later developmental stages, when soil moisture becomes scarce (Slafer et al. 2005; Richards 2006; Rebetzke et al. 2007; Richards et al. 2007). Time is an important parameter to be taken into consideration since it impacts crop yield and it is strongly influenced by environmental adaptation (Ulukan 2008). The major strategy that the plant use to deal with the decreased water availability is to escape drought (Sherrard and Maherali 2006). Consequently, it completes its life cycle before the most intense period of dehydration (Bazzaz 1979; Geber and Dawson 1990; Arntz and Delph, 2001; McKay et al. 2003) whereas delayed flowering reduces chances of seed-set in environments where high risks of mortality persist throughout the life of the plant (Ritland 1983).

Sites that were considered as dry such as Bcharre, Falougha, Baskenta, Mtein and Tarchich were the ones that fell at high altitudes as solar radiation increases with the altitude (Tranquillini 1964). Based on that, accessions that showed drought tolerance indicator characters are those that can be reintroduced in the driest areas. Those species are *M. polymorpha* from Chwaifat, *M. polymorpha* from Shebenieh, *M. truncatula*, *M. orbicularis* from Jeita and *M. constricta* from Bwerij.

Al-Atawneh et al. (2009) noted the presence of 37 species of *Medicago* in Lebanon. This study confirmed the presence of 19 different species from 37 different sites. Morphological analysis revealed that Lebanese *Medicago* germplasm is characterized by prostrate to semi prostrate growth habit. In fact, the growth habit reflects an adaptation form observed in Mediterranean climate vegetation. The early prostrate growth habit allows winter annuals to occupy a warm microenvironment when air temperature is too low for optimum plant growth (Mulroy and Rundel 1977).

The most frequent leaflet shape was lanceolate. A serrate to incised leaflet margin prevailed in *Medicago* populations. In fact, leaf dissection is a specific feature for winter annuals. Summer annuals have entire leaf shape while winter annuals have a dissected one. This trait has an adaptive value because dissected leaves halt the water loss and maintain

Table 4 Correlation between some pheno-morphological traits and ecogeographical conditions

	Early vigour	Days to flowering	Days to podding	100 seed weight	100 pod weight	Seed weight		Leaf pubescence	Early vigour	Days to flowering	Altitude	Annual precipitation	Temperature
Early vigour	1						Leaf pubescence	1					1
Days to flowering	− .345**	1					Early vigour	.002	1				1
Days to podding	− .312**	.981**	1				Days to flowering	.288**	− .345**	1			1
100 seed weight	.421**	− .326**	− .300**	1			Altitude	.247**	− .058	.534**	1		
100 pod weight	.445**	− .323**	− .284**	.743**	1		Annual precipitation	.175*	− .050	.525**	.801**	1	
Seed weight	.184*	− .073	− .050	.130	0.037	1	Temperature	− .118	.064	− .355**	*.697	− .674**	1

**Pearson correlation is significant at the 0.01 level (2-tailed); *Pearson correlation is significant at the 0.05 level (2-tailed) cooler surfaces by allowing a greater air exchange (Givnish and Vermeij 1976; Givnish 1988). Another strategy developed by annual plants to avoid tissue dehydration and protect itself from ultra violet damage is the dense trichome layer (Larcher 2000). It reduces gas exchanges and leaf heating by increasing reflectance (Monneveux and Belhassen 1996).

Long and hard spines characterized the pods. These characteristics represent an impediment to seed predators by making them less palatable (Bullitta et al. 1994).

The analysis of early vigour, flowering and pod formation within the species also showed high variation. Analysis of coefficient of variation showed that 13 characters have a coefficient higher than 50%. High diversity among *Medicago* populations was also tested in four Tunisian populations of echinus medic (Badri et al. 2008) and in Sicilian populations of burr medic (Graziano et al. 2010). According to Marshall (1975), alleles that are common can be easily conserved as they will be included in small samples. Conversely, when alleles are rare, adequate conservation is limited by sample size. Accordingly, the number of alleles originated from a population will increase with the increase in sample size. In other words, when sample size increases, the number of alleles captured will be higher.

Regarding correlations between pheno-morphological and agronomical characters, various genetic traits control early vigorous growth (Rebetzke et al. 2007). Plants with higher early vigour tend to influence flowering time. This was demonstrated by the negative correlation observed between early vigour and flowering time. In fact, when early vigour was high, days required for formation of the first flowers were reduced. Positive correlation between early vigour and seed and pod size imply that high early vigour induces a larger seed and pod size. Those results match the findings obtained in Sardinian population of *Medicago polymorpha* (Bullitta et al. 1994).

A high significant positive correlation was observed between required days to flowering and days to pod formation, meaning that the earlier the flowering occurs, an early pod formation is witnessed. Accordingly, one of these two characters could be chosen for the correlation study between pheno-morphological characters and eco-geographic factors. A negative correlation is present between flowering, 100 seed weight and 100 pod weight, meaning that larger pods and seeds are the early flowering ones. Those results are consistent with Berger et al. (2002) and Jabri et al. (2016).

On the other hand, significant correlations were found between eco-geographical factors and pheno-morphological characters; they are related to weather conditions, particularly altitude, temperature and annual precipitation of the sites of origin. A positive correlation existed between days to flowering and the altitude. The findings are consistent with those obtained by Jabri et al. 2016 for Tunisian Echinus Medic (*Medicago ciliaris* L.). As the temperature decreases at high elevations (Tranquillini 1964), this explains the negative correlation that existed between temperature and altitude. According to the high significant correlation between the flowering and the pod formation, so the latter is also considered an adaptive trait to drought. Early pod formation reflects a better partitioning of assimilates. This is due to the plant's ability to store reseves in some organs in order to mobilize them for the fruit set (Rodrigues et al. 1995; Yang et al. 2001).

This study filled agap by preserving high priority species at the ICARDA gene bank. Moreover, it has identified the sites where the species have displayed drought tolerance and are subject for further in situ conservation or reintroduction in dry areas. The fulfillment of this goal will be enhanced by the development of legislations and policies and by increasing awareness among national actors involved in the conservation of these crops.

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Data availability All data created during this research is openly available from the ICARDA database which available online via Genesys [https://www.genesys-pgr.org/].

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Human or animals rights This article does not contain any studies involving humans or animals performed by any of the authors.

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