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Collection and agro morphological characterization of Algerian accessions of lentil (*Lens culinaris*)

DJOUHER GAAD[1,2,♥], MERIEM LAOUAR[1], FATIMA GABOUN[3], AISSA ABDELGUERFI[1]
[1]Department of Plant Science, Higher National Agronomic School. Av. Hassan Badi, El Harrach, Algiers Province, Algeria. Tel.: +213-23-828507,
[♥]email: d.gaad@crbt.dz
[2]Division of Agriculture and Biotechnology, National Research Center for Biotechnology, Constantine, Algeria
[3]National Institute for Agronomic Research, Regional Center of Rabat, B.P. 6356-Rabat-Instituts, Morocco

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Abstract. *Gaad D, Laouar M, Gaboun F, Abdelguerfi A. 2018. Collection and agro morphological characterization of Algerian accessions of lentil (Lens culinaris). Biodiversitas 19: 183-193.* Lentil is one of the important pulse crops in Algeria. The narrow genetic base of local cultivars and the disappearance of many local accessions contribute to the loss of lentil biodiversity. Therefore, collection, characterization and preservation of existing local accessions of lentils are important. Lentil accessions were collected across different agro-ecological zones of Algeria. From 10 regions (Departments), 15 villages were surveyed and 30 accessions were collected. Eighteen local accessions and 26 references collection have been used for agro morphological evaluation. The assessment was performed in two locations, sub-humid and semi-arid conditions, based on 12 quantitative characters. The result of variance analysis shows a significant effect of the interaction genotype x location for six quantitative traits. Three macrosperma Algerian accessions characterized by a high number of pod/plant, number of seed/plant and seed yield/plant were positioned on PCA1. The remaining Algerian accessions were positioned on PCA2 and were characterized by later flowering and maturity with high plant stature and height of the lowest pods. Hierarchical cluster analysis grouped the accessions into five distinct clusters independently of the accessions origins and revealed the distribution of Algerian accessions in all of the groups. This study will help breeders to better select accessions to be used in lentil breeding program.

Keywords: Agro-morphological evaluation, *Lens culinaris*, local accessions, reference collection, quantitative traits

INTRODUCTION

Lentil (*Lens culinaris* Medikus) is the oldest pulse crop with remains found alongside human habitation up to 13,000 years BC (Sandhu and Singh 2007). It has been cultivated in the most difficult agricultural environments, being perhaps second only to barley in this sense (Cubero et al. 2009). Currently, it is mainly grown in semi-arid regions of South Asia, North America, Australia and Africa (Kaur et al. 2014; Verma et al. 2014). In lowland Mediterranean environments, lentil is usually grown between 300 and 400 mm annual rainfall (Ceccarelli et al. 1994). In Algeria, it is cultivated under rainfed conditions in different agro-climatic zones in regions where the annual average rainfall ranges between 300 and 900 mm. But production has dropped over the last few decades being 63.18 tons with yield about 114 kg/ha in 2014 (FAOSTAT 2017). The origin of this decline is due to many causes, the most important is the abandon of local germplasm well adapted to different environments, in profit of introduced materials. Thus, for more efficient utilization of local germplasm, the collection and characterization of local genetic resources of lentil are the first steps to take before starting any improvement program.

Assessment of genetic diversity based on phenotype has been conducted worldwide (Asghar et al. 2010; Roy et al. 2012, 2013; Pratap et al. 2014). However, a limited number of studies have been led to characterize Algerian's lentil germplasm. Therefore, the present study was undertaken to (i) collect local lentil accessions on farms through Algeria, and (ii) to determine agro-morphological traits variation among some accessions collected along with the reference collection.

MATERIALS AND METHODS

Study area

Collection trips were made throughout Algeria in 2011 at different agro-climatic zones which are characterized by variation in altitude, annual rainfall, temperature and vegetation. In order to suitably cover the study area, 15 surveyed rural area or villages were randomly selected throughout 10 Departments (Figure 1). Information characterizing each location (name of sites, name of the village/district and name of department) is summarized in Table 1.

Field evaluation

Plant materials

A total of 44 accessions of cultivated lentil (*Lens culinaris* Medik.), comprised landraces and modern cultivars representing geographically and phenotypically wide variation, were used in this study. Among these, 18 were collected in Algeria (nine microsperma and nine macrosperma). In addition, a collection reference of 26 accessions including released popular cultivars and selected advanced lines were received from ICARDA (eight accessions), USDA (twelve accessions) and ATFCC (six accessions) under standard material transfer agreement during 2011. Relevant passport data of these accessions are given in Table 1.

Experimental design

Two field experiments were conducted in two consecutive years of 2011/2012 and 2012/2013. The summary of the environmental conditions of the two trials is shown in Table S1. The first experiment was carried out at the INRAA experimental station at 18.5 m altitude in a sub-humid zone. The soil was clay- muddy with a 7.9 pH (Issolah 2007).The second field trial was located at the ITGC (Institut Technique des Grand Cultures) experimental farm in the Constantine district in the semi-arid region, about 713 m above sea level.

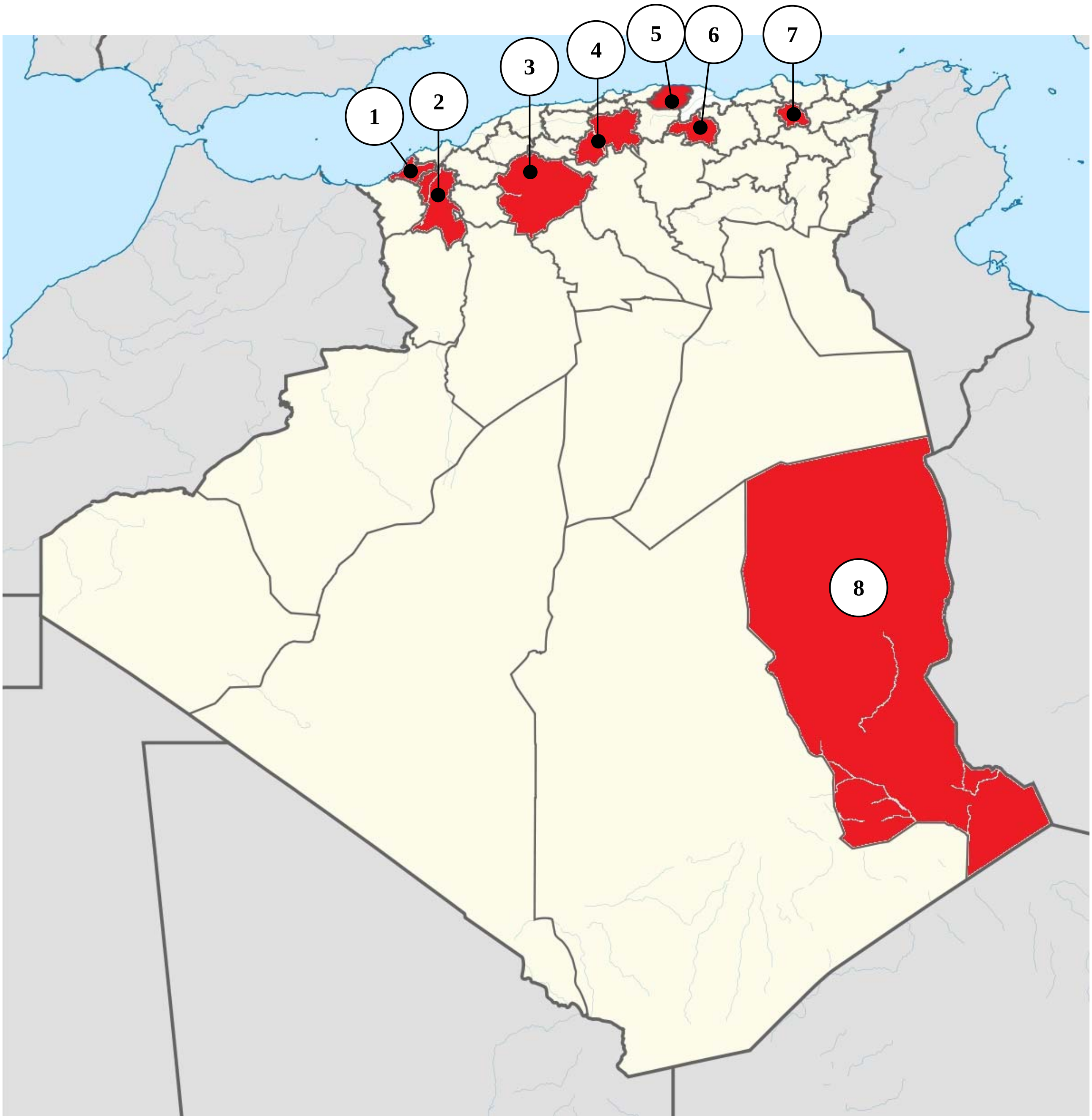

Figure 1. Map of Algeria, representing only the 8 departments where the 18 accessions used in agro morphological evaluation were collected. 1. Ain-Timouchent, 2. Sidi-Bel-Abbes, 3. Tiaret, 4. Medea, 5. Tizi Ouzou, 6. Bouira, 7. Constantine, 8. Illizi

A durum wheat crop had been grown during the previous season for both experimental locations. Sowing was performed on 9 December 2012 at the INRAA station and on 7 January 2013 at the ITGC station. The 44 entries were arranged in an incomplete randomized block design (Alpha Lattice Design) with 4 replications. Four incomplete blocks with 11 plots each were designed in each complete block. Experimental evaluation plots consisted of 3 rows of 1 m, 100 cm apart, giving a plot size of 3 m2. Seeds were sown by hand by placing 2-3 seeds in a hole and then thinning to one plant per hole by hand at seedling stage. All recommended cultural practices and plant protection measures were followed to raise a healthy crop.

Phenotypic data

The standard descriptors for lentil (IPGRI 1985, UPOV 2013) were used as guidelines in the phenotypic characterization. Observations were recorded from 4 replications of 3 plants. The detail of all traits taken into account is given in Table S2.

Statistical methods

PROC GLM within Statistical Analysis System (SAS) version 9 was used for the statistical analyses of quantitative data. Treatment means were compared statistically using Student-Newman-Keuls test at p=0.05. The relationships between quantitative traits were examined using simple correlation analysis based on Pearson's Correlation Coefficient by Excel software, 2013.

A standardized matrix was subjected to principal component analysis to study the structure of variation of the studied accessions. The nearest neighbor option based on Euclidean distances was used to explore relationships among the accessions which were performed using Ward's minimum variance method. PCA and cluster analysis were performed with XLSTAT v13.01 software (XLSTAT software (Addin Soft, New York, USA). Significance was determined a priori at alpha = 0.05 probability.

RESULTS AND DISCUSSION

Analysis of variance

Analyze of variance was performed on 12 quantitative characters and the result for individual and combined data are reported in Table S3. The mean phenotypic values of the six significant characters for both locations are presented in Table 2.

Single location

Location showed considerable differences for studied traits between accessions. Therefor there are location effects for the following characters: time to emergence, time to flowering, time to maturity, number of pods/plant, number of seed/plant and seed yield/plant.

The effect of location was height significant for time to emergence. TEM was earlier at Alger location (mean 17.80 DAS), and late at Constantine location (mean 23.21 DAS). If average data of the two locations are considered, microsperma types IG5514 (breeding materiel) from Turkey and PI431640 (hybrid line) from Iran were the first to be emerged (15 DAS), whereas the local population ALG4, macrosperma type was the last one to be emerged (27.5 days after sowing).

Location effect is very significant ($p < 0.001$) on the character FD50. At Alger location the days to flowering ranged between 95 and 125 DAS with a mean of 108.82 DAS. The local population ALG31, the improved line PI619099 (USA), the cultivated variety ILL5228 (Australia) and PI472126 (India) were the earliest for 50% flowering (100 DAS) and all microsperma type except the last one. Whereas, IG5511 from Syria macrosperma type was later in flowering (mean 117.50 DAS). At Constantine location flowering time was delayed ranged between 110 and 133 DAS with a mean of 117.19 DAS. ALG31 was the earliest one (112.25 DAS) and a later one was a breeding materiel (IG4872) from Afghanistan (123.66 DAS) a microsperma type.

Early maturing genotype at Alger was the local accessions ALG16 with 172 DAS and at Constantine the early genotypes were also local: ALG16; ALG19 and ALG22 with 148 DAS.

At Alger location the maximum number of pods/plant was produced by the genotype ALG3 (645) followed by PI490289 (572.5), however, genotype IG4872 produced minimum pods (142.5). At Constantine, a maximum pod of plant was 697.5 obtained by accession PI533690 and minimum pods of plant were noticed in accessions PI468902 with 227.5.

Variation was observed for number of seeds/plant over the two locations. The local genotype ALG3 recorded the highest number of seeds per plant (1073) at Alger, the minimum number was obtained by IG4872 (232.5). At Constantine the highest number of seeds per plant (1318) was recorded by PI472126 and the minimum one by ALG23 (306.6).

The seed yield/plant was influenced by location. It was higher at Alger (23 g/plant) and lower at Constantine (19.59 g/plant). Strong yield differences were observed among lentil accessions for both locations. Accessions that showed the highest grain yield were a local accession macrosperma type (ALG3), PI486127 from USA at Alger and PI486127 at Constantine (40.89g/plant). The accessions with the lowest grain yield were the microsperma type accession PI431640 at Constantine (6.35g/plant) and IG4872 from Afghanistan (microsperma) line at Alger.

Combined locations:

Plant height (PHT), measured from ground level to the plant tip, varied significantly ($p < 0.001$) across genotype x location. The maximum height was attained by the Australian cultivar ILL5728 (40.9 cm) followed by another Australian genotype V69-1001 with 39.9 cm. While the shortest plant was IG5160 (20.6 cm) from Jordan. The Algerian accessions had intermediate values for plant height.

Genotypes x location interaction were significant for height of the lowest pods above the soil (HLP). The

Algerian variety ALG6 (microsperma type) had the greatest value for height of the lowest pods (14.9 cm), and the lowest value was recorded for ILL5722 (microsperma type) from Australia about 9.6 cm. The overall mean for HLP was 12.4 cm.

Time to maturity was influenced by genotype x location. Early maturing genotypes included ALG16 (local population-microsperma type) with 162 days followed by the local hybrid line ALG19 with 163 days. The latest maturing genotype was also a local population of macrosperma type (ALG15) at 172 days.

It was observed that the weight of 100 seeds (SWE) differed between accessions for genotype x location. The grand mean was 3.4 g and mean values varied from 2.5 to 5.2 g. The heaviest weight was detected in the Algerian variety Bland de Chili, ALG12 (5.2 g), belonging to macrosperma type and the lightest weight (2.5 g) was the microsperma genotype from the USDA collection (PI320937) originating from Germany.

Significant variation for seed diameter was detected for genotype x location. It varied from 3.1 mm to 7.1 mm with an average of 5.2 mm. The large diameter was observed in two local macrosperma type accessions ALG12 (6.5 mm) followed by Ibla (ALG8, 6.2 mm), and the smallest one was also recorded in a local microsperma type population ALG16 (3.9 mm).

Seed thickness differed among genotype x location. STH ranged from 1.3 mm to 3.1 mm with an average mean of 2.5 mm. Microsperma accession ALG16 had the greatest thickness (2.9 mm) and ALG18 (a cultivated variety: Radjas) macrosperma type had the least (2.0 mm).

Correlation between characters

Time to maturity was negatively correlated with seed thickness ($r=-0.33$, $p<0.001$). Plant height had a significant positive correlation with height of lowest pods ($r=0.41$, $p<0.001$). Pod number is the prime yield attribute in lentil, and the number of pods/plant was positively correlated with the number of seed/plant ($r=0.88$, $p<0.001$) and seed yield/plant ($r=0.70$, $p<0.001$). On the other side, SYP was positively correlated with NSP ($r=0.77$, $p<0.001$) and seed diameter ($r=0.45$, $p<0.001$) (Table S4).

Principal compound analysis

Table S5 summarizes the PCA estimates among the tested lentil accessions. A two-dimensional (2D) plot was obtained using the first two PCs, which explained 48.8% of the total phenotypic variation (Figure 2). The first PC axis explained 27.4% of the total variation, and was mainly defined by number of pods/plant, number of seeds/plant and seed yield/plant. The second PC explained 21.4% of the total variation and was correlated with time to maturity, plant height, height of lowest pods, 100 seed weight and seed diameter. Based on the 2D graph analysis, 5 major classes were formed. Algerian accessions were distributed along the two axes and were disseminated in all 5 classes. The first class contained all microsperma types characterized by low number of pods/plant, number of seeds/plant and seed yield/plant. Class 2 contains primarily Algerian accessions belonging to macrosperma type with high plant height and lowest height for pods above the soil, late flowering and maturity, high seed weight and large seed diameter. The third class contained mainly microsperma types which are early to flower and mature with short plants, low height to the first pods, low seed weight and small seed diameter. The class group contained mainly macrosperma types that were characterized by a high number of pods/plant, number of seeds/plant and seed yield/plant. The fifth class was characterized by accessions with greater seed thickness.

Cluster analysis

The dendrogram performed by cluster analysis confirmed the PCA results and indicated that the 43 lentil genotypes could be divided into two major groups with subgroups each (Figure 3). Specifications for each cluster are presented as fellow: (i) The first group includes 16 accessions, mainly microsperma types (ALG8, ALG6, PI619099, Cassab, IG5511, PI297787, ALG28, ALG30, IG1647, ILL5728, IG4872 and V69-1001, ALG12, ALG18, ALG15 and ILL1828). The majority of Australians accessions were represented in this group. The Algerian variety Blond de Chili (ALG12) originating from Chili was clustered with a Chilean accession ILL1828 in the same subgroup. (iii) The second group includes 27 accessions, where the first subgroup contains 10 accessions exclusively microsperma types (ALG16, ALG23, ALG21, PI468902, PI320936, PI431640, ILL5722, IG26, PI320937 and ALG31). The second subgroup consisted of 17 accessions mainly microsperma types and included: ALG19, PI374119, ALG25, IG572, ALG4, PI374120, PI533690, IG8, ILL5823, ILL7180, ALG7 and IG5160. The third subgroup contains five accessions mainly macrosperma types: PI490289, ALG3, PI486127, PI472126 and ALG22.

Discussion

The collecting missions during 2011 allow us to collect 30 accessions of lentil; among them, 11 were local populations or landraces. This shows that despite the intensive modern agricultural practices and the use of modern varieties and hybrid line, there is still a tradition of cropping lentil among the small farmers. In this study, only 18 collected accessions were used for agro-morphological evaluation.

The results of ANOVA for quantitative traits indicated the influence of climatic conditions on phenological, biometric and traits related to yield. Alger is characterized by a sub-humid climate, with winter rainfall. The first trial (2011/2012) was exceptional with semi-arid condition (annual rainfall of 227 mm) as well as in Constantine location (annual rainfall of 292.1 mm). According to Erskine et al. (1994) in the Mediterranean regions of West Asia and North Africa, lentil is usually grown in areas of 300-400 mm rain year-1.

It could be predicted that local accessions should perform better than the introduced ones, since they are expected to be more adapted. However, we noticed that some accessions, especially from Australia performed better than the local genotypes. This shows that lentil has a large range of adaptability to different environments.

The lentil plants are indeterminate and they come to flower after a period of vegetative growth, the length of which varies considerably between genotypes grown in a single location (Saxena 2009). In this work, accessions showed a range 95 to 133 days, grand mean was 112.97 days. Flowering time varies considerably over the two locations. Summerfield et al. (1985) concluded that temperature and photoperiod modulate flowering in lentil. We noticed that the accession from Afghanistan is the later one at Alger location, Erskine et al. (1989) reported that on average Afghan germplasm is among the latest to flower in the world. Under sub-tropical condition with five promising lentil mutants, Alam Mondal et al. (2013) report that the mean of days to flower is 58.71. Whereas, with thirty five advanced breeding lines of lentils introduced from ICARDA tested in Saudi Arabia, days to flower was 102.8 (Alghamdi et al. 2014). Saxena (2009) reported that the duration of flowering of a single plant and crop stands enormously; it may range from less than 10 days to longer than 40 days depending on the genotype and the environment. Erskine et al. (1994), later found that the dissemination of lentil around the world has resulted in the selection of different regionally specific balances between photoperiod and temperature for the control of flowering. In order to understand the structure of the world lentil collection, landraces held at ICARDA were characterized into four major regional groups identified through analysis of variability in quantitative and qualitative morphological traits (Erskine et al. 1989). These were the Levantine group (Egypt, Jordan, Lebanon and Syria), the northern group (Greece, Iran, Turkey, USSR, and Chili), the Indian subcontinent group and the Ethiopian group. In our study accessions from Jordan and Syria were late in flowering in both locations and those from Greece, Iran, Turkey, USSR and Chili were intermediate in flowering. While, the one accession from Indian was earlier.

Plant height ranged between 13.3 and 65.0 cm with a mean of 31.6 cm. We noticed that local accessions were intermediate in stature at Alger and had high stature at the Constantine location. Saxena (2009) reported that depending on genotype and the growth environment, the plant height may range from 15 to 75 cm. He also stated that plant height is highly influenced by environment. Under water stress and in a semi-arid environment, Turk et al. (2004) reported that lentil plants at the semi-arid location had greater plant height than those grown in an arid location. Among 50 lentil advanced genotypes from ICARDA tested at Pakistan, plant height range from 36 to 66 cm with a mean of 50 cm (Bakhsh 1993). Similar results were reported by Lazaro et al. (2001) among 101 Spanish landraces. Whereas, in Saudi Arabia, Alghamdi et al. (2014) found that the mean plant height was 31 cm in five advanced breeding lines of lentils introduced from ICARDA. Tullu et al. (2001) confirmed that plant height at maturity was not only affected by genotype but also by the environment through evaluation of a core collection of lentil germplasm comprising 287 accessions from diverse geographical origins and 15 registered cultivars grown under conventional and no-till production systems in Washington state, USA.

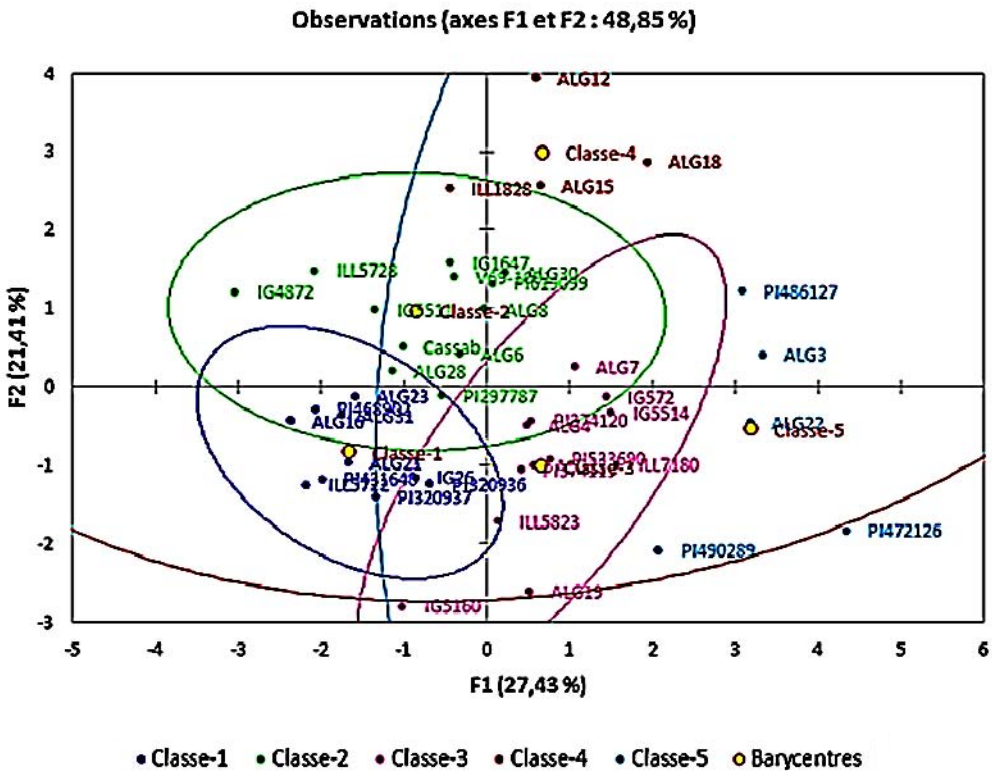

Figure 2. Scatter diagram with the distribution of 43 accessions of lentil according to the first two principal components (PC1 and PC2.

Table 1. Detail of 44 lentil accessions used in Agro morphological evaluation

Accessions code	Accession name	Status	Site/department or country	Origin	Seed type
ALG3.lens	Unknown	Population	Azrou/Tizi Ouzou, Algeria	Farmers	Macrosperma
ALG4.lens	Unknown	Population	Ikharban/Tizi Ouzou, Algeria	Farmers	Macrosperma
ALG6.lens	Syrie229	Cultivated variety	Sebien/Tiaret, Algeria	ITGC	Microsperma
ALG7.lens	Balkan755	Cultivated variety	Oued lilli/Tiaret, Algeria	ITGC	Microsperma
ALG8.lens	Ibla	Cultivated variety	Dahmouni/Tiaret, Algeria	ITGC	Macrosperma
ALG12.lens	B. de Chili	Cultivated variety	Ain Trid/Sidi-Bel-Abbes, Algeria	ITGC	Macrosperma
ALG15.lens	Unknown	Population	Targa/A.Timouchent, Algeria	Farmers	Macrosperma
ALG16.lens	Unknown	Population	Aghlal/A.Timouchent, Algeria	Farmers	Microsperma
ALG18.lens	Radjas	Cultivated variety	Bouskin/Medea, Algeria	ITGC	Macrosperma
ALG19.lens	Flip 90 31C	Hybrid line	Bouskin/Medea, Algeria	ITGC	Macrosperma
ALG21.lens	Setif628	Cultivated variety	Bouskin/Medea, Algeria	ITGC	Microsperma
ALG22.lens	Flip 48 L	Hybrid line	Bouskin/Medea, Algeria	ITGC	Microsperma
ALG23.lens	Flip 97-11C	Hybrid line	Bouskin/Medea, Algeria	ITGC	Microsperma
ALG25.lens	Metropole	Cultivated variety	ElKhroub/Constantine, Algeria	Farmers	Microsperma
ALG28.lens	Unknown	Population	Khbouziya/Bouira, Algeria	Farmers	Macrosperma
ALG29.lens	Unknown	Population	Illoula/Tizi Ouzou, Algeria	DSA	Macrosperma
ALG30.lens	Metropole	Cultivated variety	Ifigha/Tizi Ouzou, Algeria	DSA	Microsperma
ALG31.lens	Unknown	Population	Djanet/Illizi, Algeria	Farmers	Microsperma
IG5511	Unknown	Breeding material	El-Hasakah/Syria	ICARDA	Macrosperma
IG1647	Cundina	Unknown	Bogota/Colombia	ICARDA	Microsperma
IG26	ILL26	Unknown	Damascus/Syria	ICARDA	Macrosperma
IG1828	ILL1828	Unknown	Bio Bio/Chili	ICARDA	Macrosperma
IG8	ILL8	Improved cultivar	Amman/Jordan	ICARDA	Microsperma
IG572	ILL572	Breeding material	Tunceli/Turkey	ICARDA	Microsperma
IG5160	ILL5160	Breeding material	Irbid/Jordan	ICARDA	Microsperma
IG4872	DEU146	Breeding material	Kabul/Afghanistan	USDA	Microsperma
PI431640	ILL1017	Hybrid line	Iran	USDA	Microsperma
PI619099	Mason	Improved cultivar	Washington/USA	USDA	Macrosperma
PI374120	ILL1941	Other	Morocco	USDA	Macrosperma
PI490289	Mariette	Cultivar	France	USDA	Macrosperma
PI486127	Unknown	Breeding material	Washington/USA	USDA	Macrosperma
PI320936	Daghestan	Unknown	Russia	USDA	Microsperma
PI468902	Unknown	Population	Rio G.do sul/Brazil	USDA	Microsperma
PI320937	ILL505	Unknown	Germany	USDA	Microsperma
PI297787	ILL319	Unknown	Greece	USDA	Microsperma
PI533690	PARDINA	Unknown	Spain	USDA	Microsperma
PI472126	33-0690000	Unknown	Uttar Pradesh/India	USDA	Microsperma
PI374119	ILL1940	Unknown	Morocco	USDA	Microsperma
V69-10010	Flash	Improved cultivar	Victoria/Australia	ATFCC	Microsperma
ILL5722	Digger	Improved cultivar	Victoria/Australia	ATFCC	Microsperma
ILL5728	Cobber	Improved cultivar	Victoria/Australia	ATFCC	Microsperma
ILL5823	Matilda	Improved cultivar	Victoria/Australia	ATFCC	Microsperma
ILL7180	Nugget	Improved cultivar	Victoria/Australia	ATFCC	Microsperma
Unknown	Cassab	Improved cultivar	Victoria/Australia	ATFCC	Microsperma

Height of the lowest pods above the soil is an important character for mechanization in lentil. A microsperma Algerian variety Syrie 229 (ALG6) had the greatest height to the lowest pods in this study. Bacchi et al. (2010) reported greater values in macrosperma than microsperma types among 25 lentil accessions representing part of a large germplasm collection from different Mediterranean regions including three Algerian landraces. In Turkish landraces, the height of the lowest pod above the soil ranged between 21.7 and 41.6 cm, with a mean of 30.2 cm (Toklu et al. 2009). Piergiovanni (2000) reported that the height of the lowest pods was between 11 and 26 cm in Italian lentil populations, the mean height was 24.2 cm. However, for 'Colliano', a microsperma morpho-type from Italy, the distance of the first pod from ground was 26 cm (Zaccardelli et al. 2012).

Indigenous or local accessions were both earlier (161.71 days) and later (172 days) in maturity. While, introduced accessions were intermediate in maturity except some accessions from Turkey, USA, Chili and Afghanistan which matured late. Erskine et al. (1989) reported that on average Afghan germplasm is among the latest in maturity in the world. Torricelli et al. (2012) found that Italian landraces mature after 78 days. In pigeon pea, accessions from Oceania were the earliest to mature (179 days) as reported by Upadhyaya et al. (2005). Among 113 desi chickpea genotypes, days to maturity ranged between 144.0 and 180.0 with a mean of 171.1 days (Riaz et al. 2014). For sixty-four lentil genotypes from ICARDA evaluated at Diyarbakir in Turkey, days to maturity ranged from 188 to 196 days, and some genotypes were earlier than the local check (Biçer and Sakar 2008). In nine inter-sub-specific and interspecific crosses in lentil, days to maturity ranged from 71.6 to 159.4 days (Singh et al. 2014). Erskine et al. (1994), found that the dissemination of lentil around the world has resulted in the selection of different regionally specific balances between photoperiod and temperature for the control of flowering and maturity.

Table 2. Mean values, coefficient of variation (%) and standard error for six quantitative traits recorded at Alger and Constantine, Algeria

Accessions	**Time to maturity (days)**	**Plant height (cm)**	**Height to lowest pod (cm)**	**100-seed weight (g)**	**Seed diameter (mm)**	**Seed thickness (mm)**
ALG16	161.71_{l}	39.18_{abc}	12.42_{abc}	3.11_{cd}	3.93_{q}	2.86_{a}
ALG8	167.50_{a-j}	35.74_{a-e}	12.62_{abc}	3.89_{bcd}	6.24_{ab}	2.80_{ab}
ALG6	165.50_{e-l}	32.28_{b-g}	14.87_{a}	3.06_{cd}	4.82_{h-o}	2.74_{a-c}
ALG23	163.50_{i-l}	29.04_{e-i}	12.12_{abc}	3.86_{bcd}	5.47_{c-i}	2.68_{a-d}
ALG21	162.50_{kl}	25.54_{g-j}	11.87_{abc}	3.49_{bcd}	5.18_{f-l}	2.63_{b-e}
PI619099	170.00_{a-e}	33.87_{a-g}	14.62_{a}	3.07_{cd}	5.59_{b-h}	2.60_{b-f}
ALG19	162.00_{l}	23.33_{ij}	10.50_{abc}	3.31_{bcd}	5.36_{d-i}	2.60_{b-f}
PI468902	166.50_{c-l}	30.52_{d-i}	11.00_{abc}	3.05_{cd}	4.55_{o-n}	2.19_{kl}
IG5160	164.83_{f-k}	20.55_{j}	10.00_{bc}	3.11_{cd}	3.99_{qp}	2.60_{b-f}
PI320936	164.50_{g-l}	24.41_{ijh}	11.37_{abc}	4.54_{ab}	2.85_{b-h}	2.56_{c-g}
PI431640	167.00_{b-i}	27.03_{f-h}	12.25_{abc}	2.85_{cd}	4.80_{g-o}	2.56_{c-g}
PI374119	163.00_{j-l}	33.74_{a-g}	11.00_{abc}	2.82_{cd}	4.81_{h-o}	2.55_{c-g}
ALG12	169.50_{a-f}	37.78_{a-d}	14.50_{ab}	5.23_{a}	6.46_{a}	2.55_{c-g}
ALG25	164.00_{k-l}	30.27_{d-i}	12.25_{abc}	3.40_{bcd}	4.62_{o-n}	2.52_{c-h}
ILL5722	166.00_{d-l}	29.33_{e-h}	09.62_{c}	3.55_{bcd}	4.92_{h-n}	2.49_{c-i}
Cassab	169.00_{a-f}	32.58_{b-h}	12.62_{abc}	3.81_{bcd}	4.92_{h-n}	2.49_{c-i}
IG572	171.50_{ab}	33.12_{b-g}	12.25_{abc}	2.89_{cd}	4.58_{o-n}	2.49_{c-i}
IG26	163.00_{j-l}	28.02_{e-g}	11.37_{abc}	3.68_{bcd}	5.19_{f-l}	2.48_{c-i}
IG5511	170.85_{a-d}	33.33_{b-g}	11.14_{abc}	3.27_{bcd}	5.72_{b-g}	2.48_{c-i}
ALG15	172.00_{a}	33.74_{a-g}	12.87_{abc}	5.09_{a}	5.59_{b-h}	2.48_{c-i}
PI297787	168.00_{a-i}	32.81_{b-g}	14.25_{ab}	2.60_{cd}	4.91_{h-n}	2.47_{c-i}
ALG4	171.00_{abc}	28.45_{e-i}	12.25_{abc}	3.21_{bcd}	3.21_{b-h}	2.47_{c-i}
ALG28	166.50_{c-l}	34.66_{b-f}	13.12_{abc}	3.29_{bcd}	5.55_{b-h}	2.46_{d-k}
PI490289	168.00_{a-i}	27.02_{f-i}	11.05_{abc}	3.16_{bcd}	5.22_{f-l}	2.45_{d-k}
PI374120	168.00_{a-i}	28.58_{e-i}	11.62_{abc}	3.64_{bcd}	4.42_{o-n}	2.44_{d-k}
ALG3	168.00_{a-i}	30.62_{d-i}	13.50_{abc}	3.70_{bcd}	6.10_{abc}	2.44_{d-k}
PI320937	164.00_{h-l}	31.74_{c-h}	12.87_{abc}	2.51_{d}	5.04_{g-m}	2.43_{d-k}
PI533690	169.00_{b-g}	30.87_{d-g}	12.12_{abc}	2.61_{cd}	4.39_{o-n}	2.42_{d-k}
PI486127	171.00_{abc}	28.16_{e-i}	14.00_{abc}	4.05_{bc}	5.99_{a-e}	2.40_{d-k}
IG5514	168.50_{b-h}	29.33_{f-i}	12.50_{abc}	3.73_{bcd}	4.89_{h-n}	2.40_{d-k}
ILL5823	164.50_{g-l}	28.45_{e-g}	12.87_{abc}	2.64_{cd}	4.73_{i-n}	2.39_{e-k}
ILL7180	167.00_{b-i}	34.70_{a-f}	12.13_{abc}	3.05_{cd}	5.09_{g-m}	2.38_{e-k}
ILL5728	170.00_{a-e}	40.91_{a}	13.00_{abc}	3.10_{cd}	4.22_{d-i}	2.37_{e-l}
V69-1001	167.00_{b-i}	39.87_{ab}	12.25_{abc}	3.84_{bcd}	4.83_{h-m}	2.35_{e-l}
PI472126	165.00_{i-j}	30.16_{d-i}	11.50_{abc}	3.42_{bcd}	5.23_{f-k}	2.34_{e-l}
IG1647	169.00_{d-l}	31.95_{b-h}	13.75_{abc}	3.42_{bcd}	3.42_{a-d}	2.33_{f-i}
ALG22	163.50_{i-l}	29.41_{e-i}	13.00_{abc}	3.55_{bcd}	6.12_{abc}	2.33_{f-i}
ALG7	166.00_{a-g}	29.08_{e-i}	12.75_{abc}	3.88_{bcd}	5.49_{c-h}	2.30_{g-l}
ILL1828	171.00_{abc}	36.04_{a-e}	14.25_{ab}	3.33_{bcd}	5.32_{e-k}	2.24_{h-l}
ALG31	166.00_{d-l}	38.41_{a-d}	11.00_{abc}	2.52_{d}	3.95_{q}	2.22_{i-l}
ALG30	170.00_{a-d}	37.70_{a-c}	12.25_{abc}	3.59_{bcd}	4.22_{o-n}	2.21_{j-l}
IG4872	170.85_{a-d}	40.91_{d-i}	12.42_{abc}	2.54_{d}	4.14_{opq}	2.12_{l}
ALG18	165.00_{i-j}	35.82_{a-e}	13.62_{abc}	5.06_{a}	5.91_{a-f}	1.97_{m}
Mean of accessions	167.00	31.64	12.42	3.44	5.15	2.45
CV (%)	1.59	14.05	18.38	21.85	8.30	6.14
LSD	0.81	0.40	0.14	0.06	0.04	0.01

Note: In a column, numbers with same letter (s) do not differ significantly at P = 0.05

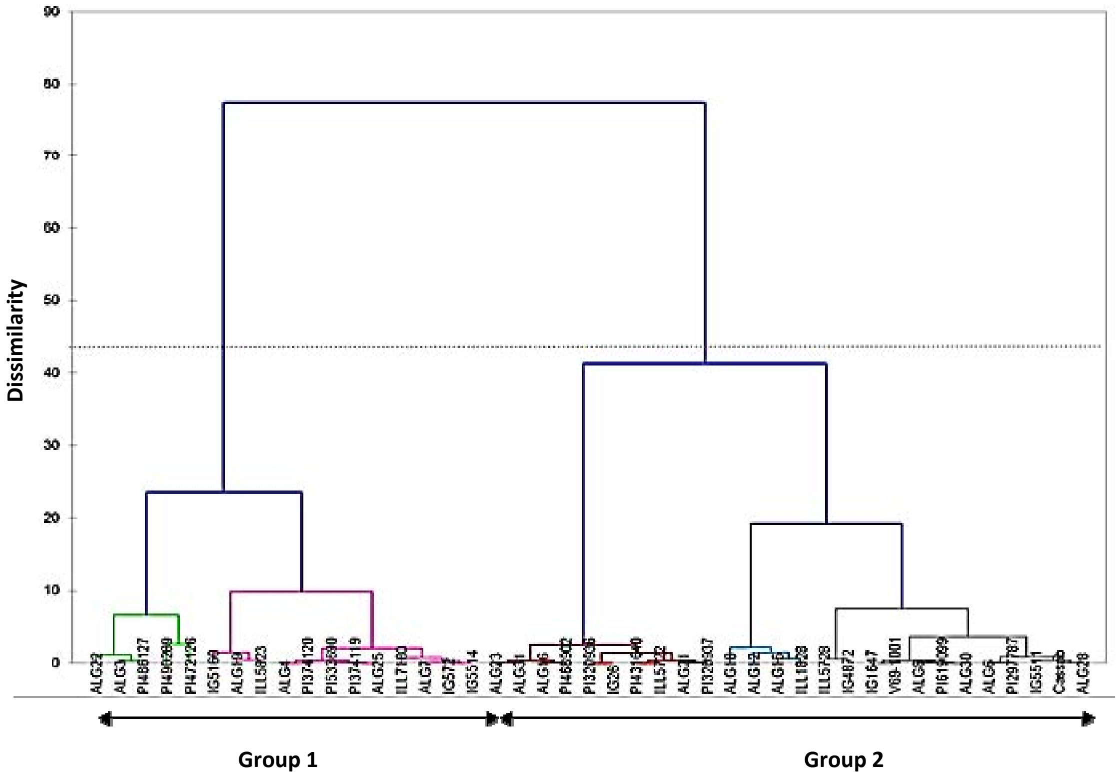

Figure 3. Dendrogram computed from the Euclidean distance for 43 lentil accessions

The environmental effect on seed weight is generally not very conspicuous as indicated by Saxena (2009). The macrosperma types manifest a high 100-seed weight compared to microsperma and the top three accessions for large 100 seed weight were Algerian accessions. The mean of all accessions was 3.4 g with a range from 1.1 g to 6.9 g. The 100-seed weight ranged from 1.1 to 4.0 g in small-seeded types, while the large-seeded types generally ranged from 4.0 to 8.2 g (Barulina 1930 in Saxena 2009). Tullu et al. (2001) reported that the variation of 100 seed weight ranged from 1.3 to 7.4 g, with an overall mean of 3.6 g in the USA lentil core collection of 287 lentil accessions. Bejiga et al. (1996) in one hundred and fifty-six landrace populations of lentil (*Lens culinaris* Medikus) collected from 10 provinces in Ethiopia said that the most important character for differentiation was 100-seed weight (2.6 g), a trait affected by human preference and of low adaptive value according to the author. Under rainfed semi-arid conditions with the Mediterranean climate in Jordan, Abdel-Rahman et al. (2002) found that 100 seed weight of local lentil cultivars was 4.3 g.

Adequate knowledge about degree and direction of the association of characters is a prerequisite for operating an efficient selection program (Mishra et al. 2007). Positive correlations have been found between seed size, seed weight, plant height, height of lowest pods and number of pods/and seeds per plant and seed yield. Correlations calculated from this research were comparable to published data (Erskine 1983; Hamdi et al. 1991; Biçer and Sakar 2008; Bacchi et al. 2010; Al-Ghzawi et al. 2011; Barghi et al. 2012; Zaccardelli et al. 2012 and Mondal et al. 2013). A negative association between seed thickness and time to maturity can be useful in selecting for variability for seed size.

Principal component analysis revealed that accessions of the same seed type grouped together. Cluster analysis revealed the existence of five groups of accessions with distinct morphological profiles. Accessions included in Group-I seem to be earlier in flowering and maturity, with intermediate plant stature, low pod height above the soil, and low number of pods, seeds and seed yield. However, accessions of Group-III had a medium number of pods and seeds/plant, 100 seed weight and seed yield/plant with thick seeds. Accessions in Group-II had taller plant stature and height of the lowest pods. Group IV comprised accessions late to flower and maturity, with high 100 seed weight and seed diameter. Whereas group-V was characterized by genotypes having large number of pods, seeds and seed yield per plant. Some groups comprise accessions possessing desirable traits that can be used in breeding.

Fikiru et al. (2010) classified seventy Ethiopian lentil landrace accessions into two clusters based on Euclidian distance considering 8 morphological traits. Tyagi and Khan (2010) reported that clustering pattern revealed the distribution of the genotypes belonging to the same origin in more than one cluster indicating non- parallelism between geographic and genetic diversity. Asghar et al. (2010) reported that metroglyph analysis distributed 30 lentil genotypes into 10 distinct groups ,the first and the second g showed close genetic relationship in respect of number of pods and seed yield.

In conclusion, the agro-morphologic results highlighted the influence of climatic conditions on phenological, biometrical and yield traits. Some accessions from other countries like Australia and India performed well despite grown in an environment different from where they originated. This shows the possibility of enhancing local germplasm by broadening the gene pool through international sources. Significant differences among the accessions for different characters indicated variation among the accessions favorable for their use in breeding programs.

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Table S1. Weather conditions (monthly means) during the two cropping seasons (2011/2012 and 2012/2013)

Climate	October	November	December	January	February	March	April	May	June	Total
Minimum T. (°C)										
2011/2012	15.3	12.7	8.2	5.6	4.00	9.4	11.6	14.0	20.2	
2012/2013	12.5	7.7	2.5	2.3	1.5	5.7	7.4	9.1	12.0	
Maximum T. (°C)										
2011/2012	24.7	21.4	17.7	16.7	13.1	18.1	20.7	24.2	29.8	
2012/2013	25.8	19.5	14.2	12.7	11.7	17.8	21.6	24.1	28.8	
Mean T. (°C)										
2011/2012	20.0	17.1	12,9	11.2	8.5	13.7	16.1	19.1	25.00	
2012/2013	18.4	12.9	07.8	06.0	05.9	11,2	13.8	16.1	20.20	
Rainfall (mm)										
2011/2012	9.00	39.0	20.0	8.00	78.0	33.0	32.0	8.00	0.00	227
2012/2013	33.4	29.4	19.0	64,0	111.9	47.4	31.0	10.0	10.00	292.1

Table S2. Descriptors used for morphological assessment for qualitative and quantitative traits of lentil in the study (IPGRI 1985; UPOV 2013)

Descriptors	Code	Definition Quantitative traits	When measured	Unit
Time to emergence	TEM	Number of days from sowing until 90 % of plants had sprouting	Seedling stage	*Days*
Days to 50 % flowering	FD50	Number of days from planting to the stage when 50% of the plants have begun to flower	Flowering	*Days*
Days from sowing to maturity	TMT	Number of days from planting to the stage when 90% of the plants have matured	Maturity	*Days*
High of the lowest pod above the sol	HLP	Mean height of first pod from ground level	Maturity	*Cm*
Plant height	PHT	Length from soil to the tip of terminal leaf at maturity	Pod-filling stage	*Cm*
Number of pods per plant	NPP	Recorded from 10 randomly selected plants	Harvest	*Unit*
Number of seeds per pod	NSP	Recorded from 10 randomly selected plants	Harvest	*Unit*
Number of seeds per plant	SPL	Recorded from 10 randomly selected plants	Harvest	*Unit*
100-seed weight	SWE	Average weight of two samples of 100 randomly chosen seeds	After drying	*Unit*
Seed yield per plant	SYP	Weight of goods seeds from 10 randomly selected plants	After drying	*g/plant*
Seed diameter	SDM	Diameter of 100 goods seeds	After drying	*mm*
Seed thickness	STH	Thickness of 100 goods seeds	After drying	*mm*

Table S3. Mean square values for 12 quantitative characters recorded over two sites (Alger and Constantine) from 2011-12 to 2012-13

Source of variation	DF	Time to emergence (days)	Time to flowering (days)	Time to maturity (days)	Plant height (cm)	Height to lowest pod (cm)	Pods / plant (no)	Seeds/ pods (no)	Seeds /plant (no)	100-seed weight (g)	Seed diameter (mm)	Seed thickness (mm)	Seed yield/plant (g)
Location	1	2477.77 ***	5931.06 ***	70254.4 ***	2616.54 ***	278.34 ***	466838.7 **	0.409 ns	2022235.34 **	64.94 ***	22.72 ***	0.50 ***	1320.142 **
Genotype	42	61.015 ns	63.49 ns	64.7488 ***	151.74 ***	11.56 ***	57205.01 ns	0.187 ns	207843.29 ns	3.370 ***	3.22 ***	0.22 ***	325.2363 ns
Genotype × location	42	83.23 ns	39.56 ns	32.5891 ***	122.90 ***	10.93 **	38981.48 ns	0.139 ns	154203.004 ns	1.636 ***	1.11 ***	0.11 ***	272.5662 ns
Error	238	45.02	42.75	7.05158	19.79	5.21	57005.57	0.162	188173.23	0.5659	0.18	0.02	257.74993

Note: * Significant at p≤0.05, ** Significant at p ≤0.01, *** Significant at p≤0.001

Table S4. Pearson's correlation coefficients in 43 lentil accessions among 12 quantitative characters

Traits	**TEM**	**FD50**	**TMT**	**PHT**	**HLP**	**NPP**	**SPL**	**NSP**	**SWE**	**SDM**	**STH**	**SYP**
TME	1	-0.094	-0.073	0.150	-0.110	-0.048	0.036	0.275	-0.135	-0.068	-0.128	-0.093
FD50	-0.094	1	0.200	-0.101	0.196	-0.102	-0.109	0.050	0.028	-0.078	-0.089	-0.088
TMT	-0.073	0.200	1	0.208	0.297	0.005	0.122	0.248	0.111	0.093	-0.325	0.177
PHT	0.150	-0.101	0.208	1	0.411	-0.290	-0.140	0.224	0.071	0.253	-0.204	-0.135
HLP	-0.110	0.196	0.297	0.411	1	-0.010	0.063	0.105	0.170	0.298	-0.119	0.174
NPP	-0.048	-0.102	0.005	-0.290	-0.010	1	0.876	-0.033	-0.100	-0.096	-0.079	0.698
SPL	0.036	-0.109	0.122	-0.140	0.063	0.876	1	0.416	-0.029	0.014	-0.140	0.771
NSP	0.275	0.050	0.248	0.224	0.105	-0.033	0.416	1	0.023	0.195	-0.090	0.208
SWE	-0.135	0.028	0.111	0.071	0.170	-0.100	-0.029	0.023	1	0.450	-0.059	0.541
SDM	-0.068	-0.078	0.093	0.253	0.298	-0.096	0.014	0.195	0.450	1	0.018	0.245
STH	-0.128	-0.089	-0.325	-0.204	-0.119	-0.079	-0.140	-0.090	-0.059	0.018	1	-0.175
YPL	-0.093	-0.088	0.177	-0.135	0.174	0.698	0.771	0.208	0.541	0.245	-0.175	1

Table S5. Eigen values, individual and cumulative percentage variations and Eigen vector explained by four vectors explained by four principal components based on morphological traits in 43 lentil genotypes

Axes of the principal component Analysis				**DF50**	**TMT**	**PHT**	**HLP**	**SWE**	**NPP**	**NSP**	**SDM**	**STH**
Axis	**Eigenvalue**	**Proportion (%)**	**Cumulative Proportion (%)**									
PC1	2.74	27.43	27.43	-0.050	0.152	-0.076	0.126	0.195	0.504	0.540	0.126	-0.145
PC2	2.14	21.41	48.84	0.134	0.338	0.454	0.454	0.353	-0.292	-0.180	0.405	-0.211
PC3	1.41	14.11	62.96	-0.386	-0.427	-0.080	-0.143	0.446	-0.101	-0.105	0.443	0.445
PC4	1.10	11.03	73.99	0.709	0.081	-0.540	-0.063	0.366	-0.087	-0.145	-0.017	0.131