Iran Agricultural Research (2021) 40(1) 51-60

Research Article

Shiraz University

Selection of lentil (*Lens culinaris* medik.) genotypes by assessing phenological, morphological, yield and yield attributes

J. Nabati[1]*, A. Nezami[1,2], A. Hasanfard[2], M. Zare Mehrjerdi[3], M. Rastgoo[2]

[1]Legume Department, Research Centre for Plant Sciences, Ferdowsi University of Mashhad, I. R. Iran
[2]Department of Agrotechnology, Faculty of Agriculture, Ferdowsi University of Mashhad, I. R. Iran
[3]Shirvan Higher Education Complex, I. R. Iran

* Corresponding Author: jafarnabati@ferdowsi.um.ac.ir
DOI: 10.22099/IAR.2021.39466.1427

ARTICLE INFO
***Article history*:**
Received **13 January 2021**
Accepted **14 June 2021**
Available online **11 August 2021**

***Keywords*:**
Filled Pods
Genetic Resources
Local Germplasm
Seed Yield

ABSTRACT- It is crucial to benefit from the lentil genetic resources to select them for greater economic yield and take advantage of the maximum production potential by local germplasms. Therefore, this study aimed to evaluate the phenological, morphological characteristics, yield, and yield components of 15 lentil genotypes in the Research Field, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran, in February 2019. The experiment was carried out based on completely randomized blocks with three replications. According to the results, the MLC47 genotype was superior to other genotypes with a plant height of 44.7 cm and 4.4 branches per plant. In addition, the MLC33 genotype had the most filled pods with 79.4% fertility, and no significant difference was observed between this genotype and 60% of the entire genotypes in this regard. Moreover, the MLC454 and MLC47 genotypes had the highest seed yield with 133.8 and 125 g seeds per plant, respectively. Cluster grouping and comparison of means of the groups with the total mean showed that the MLC33 and MLC454 genotypes had a higher mean, compared to other genotypes in 69% of the studied traits. So that these two genotypes could be used in future research projects to identify and select the superior lentil genotypes.

INTRODUCTION

Lentil (*Lens culinaris* Medik.) is one of the most important sources of protein, carbohydrates, calcium, phosphorus, iron and B vitamins, and widely cultivated around the world and its consumption has increased substantially in the human diet, especially in the developing countries (Giannakoula et al., 2012; Sarker et al., 2018). According to the latest FAO data, the area sown to lentil was more than 6.5 million hectares, and more than 7.5 tons of lentil were produced in 2017 (FAOSTAT, 2019). In 2017, the major producers of lentil were Canada (3.7 million tons), India (1.2 million tons), Turkey (0.43 million tons), producing about 75% of the world's lentil grain (FAOSTAT, 2019). The Iranian Agricultural Statistics revealed that the highest level of grain harvest in the crop year 2016-2017 was related to lentil (17.1%) after chickpeas (*Cicer arietinum* L.) and beans (*Phaseolus* spp.). Ardabil, East Azerbaijan, and Lorestan provinces are the largest producers of lentil in Iran (Iran Agriculture Statistics, 2017), and it is forecasted that the potential of the level of harvesting and production of this plant will increase with the improvement of factors related to production.

Given the growing population of the world, one of the most important challenges facing human beings is food production (Hall et al., 2017). In other words, it is essential to achieve new cultivars with more quantitative and qualitative production to ensure food safety in the world, especially in developing countries (Porter et al., 2014; Sehgal et al., 2019). In this respect, legumes including lentil can play a special role in providing food safety for low-income groups as a source of protein. Lentil is a cool-season legume in South and West Asia, North Africa, North and South America and Eastern Europe, and similar to other crops, its growth, fertility and yield is affected by environmental factors. As such, it is crucial to use the genetic diversity of wild relatives of legumes such as lentil to select high-yield genotypes to improve the efficiency of ecosystems of agricultural systems and the production of cultivars tolerating environmental stresses to increase crop yield and improve farm productivity (Sehgal et al., 2019). Moreover, mechanized harvesting of lentil, especially in North Africa and West Asia, is one of the most important causes of the limitation of production

(Erskine et al., 1991; Sarker and Kumar, 2011). In fact, in addition to the increase in harvest costs, manual harvesting leads to a slow harvesting process and waste of products. According to the FAOSTAT (2019), the low yield of lentil in countries such as Iran (536 kg.ha^{-1} in 2018) is among the important issues regarding the production of this product, which requires more attention to the production factors. In this context, genetic diversity is the basis of selection in breeding programs to improve traits to produce new and consistent cultivars.

Various studies have evaluated the phenological, morphological, functional properties and yield of legumes such as lentil and chickpea to determine germplasm diversity to increase the genetic potential of these products (Tsanakas et al., 2018; Upadhyaya et al., 2002). Toklu et al. (2009) evaluated the agromorphological characteristics of lentil masses collected from the southeastern Anatolia region of Turkey to select and develop cultivars resistant to environmental stresses and suitable for high-yield and suitable mechanical harvesting operations (Toklu et al., 2009). Gathering information from various study works has led to the existence of documents on agricultural and descriptive traits in lentil gene treasure in more than half of world lentil collection in the International Lentil Information System (ILIS) (Smykal et al., 2015). In order to study on the selection of chickpeas (Desi type) genotypes, Alemu et al. (2018) marked a positive and significant correlation between seed yield and the variables of plant height, number of branches and 100-seed weight. Meanwhile, there was a negative, significant correlation between seed yield and flowering and maturing days.

It is crucial to carry out plant selection to evaluate and identify top traits for adaptation to environmental factors and ultimately higher production of valuable plants such as legumes. Therefore, evaluation of the characteristics of important plants such as lentil plays a fundamental role in the selection of top genotypes for different purposes of selection and increase of yield in different climatic conditions of each region (Gaad et al., 2018). On the other hand, stability in productivity and important economic characteristics (e.g., yield) are among the main reasons for the selection of plants such as lentil (Wanare, 2015), which lays the foundation for sustainable development of products in different areas. With this background in mind, this study aimed to evaluate the phenological, morphological characteristics, yield, and yield components of 15 cold-tolerant lentil genotypes (Nabati et al., 2020) selected from the Mashhad Lentil Collection in the Research Centre for Plant Sciences of Ferdowsi University of Mashhad, Iran.

MATERIALS AND METHODS

Site Description and Experimental Design

This experiment was performed in the research field of Ferdowsi University of Mashhad, Iran (36°15’ N, 56°28’ E, 985 m altitude). Following seedbed preparation by ridge tillage in February 2019, 15 lentil genotypes (Table 1) collected from Mashhad Lentil Collection (MLC) were sown with the density of 100 plant m^{-2} (0.5m×0.02m in and on row plant spacing, respectively). Soil samples collected from the different field sites were analyzed for their physical and chemical characteristics by adopting standard procedures and depicted in Table 2. The experiment was carried out based on complete randomized blocks with three replications. Irrigation was done immediately after sowing and during the growing season according to the need of the field by furrow method. In addition, the hand weeding method was used for weed control during March and April 2019. The trend of the air temperature during the experiment is shown in Fig.1.

Table 1. Lentil genotypes used in this study and their origins

No.	Seed bank ID	Origin	No.	Seed bank ID	Origin
1	MLC[†]11	Iran	9	MLC286	Iran
2	MLC13	Iran	10	MLC303	Iran
3	MLC17	Iran	11	MLC334	Iran
4	MLC33	Iran	12	MLC407	Iran
5	MLC38	Iran	13	MLC454	Iran
6	MLC47	Iran	14	MLC469	Iran
7	MLC70	ILL[††]7679	15	MLC472	Iran
8	MLC84	ILL7723	-		

††ILL: International Legume Lentil

Table 2. The characteristics of soil samples were examined.

Texture class	pH	EC (dS m^{-1})	O.M (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})
Silt loam	7.34	2.38	0.64	0.068	16.83	112

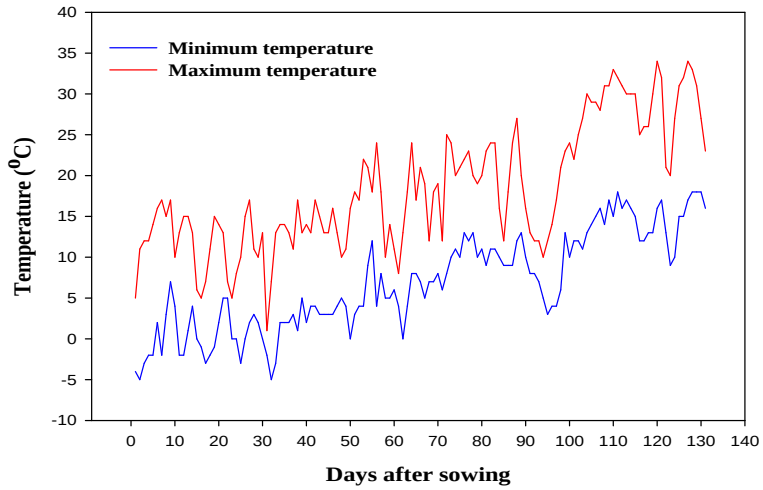

Fig. 1. Maximum and minimum air temperatures during the experiment in Mashhad, Iran

Measurements

The traits considered in this experiment were evaluated based on the lentil descriptor as follows:

Phenological Traits

Phenological traits throughout the growing season, the state of emergence and flowering of plants of each genotype were regularly evaluated and recorded, followed by the estimation of the time to reach 50% of the mentioned stages via interpolation.

Morphological Traits

Morphological traits include plant height; the average height of five plants at the end of the growing season, flower length; the average length of five plants for each genotype, length, and width of leaflets; the length and width of five leaflets from five plants at the location of the third lower leaf axis of the fifth leaf from the tip of the plant, leaf length; five leaves were selected from five plants and the average length of their leaf axis without considering the end petiole was recorded as leaf length. Notably, the JMicroVision software was applied for accurate recording of flower length, length, and width of leaflets and leaf length after imaging. To measure the leaf area, the leaf area of five plants was measured immediately after sampling by the leaf surface measurement device, and the mean was calculated as the leaf area to estimate the leaf area index (LAI) through the total leaf surface area to the ground surface unit.

Yield and Yield Components

The number of sub-branches was determined by counting the branches of five plants by the stage of ripening. The lowest pod height from the soil surface; the mean lowest pod height of five plants at the plant harvest stage. The number of pods; the mean number of pods of five plants at the plant harvest stage. The percentage of filled pods: estimated by counting the full and empty pods of five plants at the plant harvest time and dividing the number of full pods into the total number of pods multiplied by 100. In addition, the 100-seed weight of each genotype was measured with three replications. At the end of the growing season, seed and biological yield were determined by removing marginal effects and harvesting the middle plants of each plot from the level of four square meters after drying in the open air. The harvest index (HI) was measured using equation (1).

$$HI=\frac{SY}{BY}\times 100 \quad (1)$$

Where HI is the harvest index (percentage), SY is seed yield (g m^{-2}) and BY is biological yield (g m^{-2}).

Statistical Analysis

Data analysis was performed in Minitab v17, and the means were compared by Duncan's Multiple Range Test (DMRT) at a 95% confidence interval. Furthermore, the correlation and cluster analysis of data was carried out applying the JMP8 software and Ward method that divided the genotypes into four main groups.

RESULTS AND DISCUSSION

Days to 50% Emergence (D_{50e})

According to the results, a significant difference was observed among the genotypes in terms of D_{50e} (Table 3). In this regard, the D_{50e} of the plants varied from 25 to 31 days. In addition, the lowest D_{50e} was related to genotypes of MLC469, MLC286, MLC472, and MLC13, whereas the highest level of the mentioned variable was observed in genotypes of MLC33, MLC303, MLC38 and MLC454 (Table 3). A lower D_{50e}, or in other words, the faster establishment of plants on the farm, was defined as “a more efficient use of water and nutrition element resources”. On the other hand, the same favorable feature is involved in the quick closing of the canopy, which increases the power in weed/crop competition for light and the ability to photosynthesize, which ultimately improves yield in the

plant (Hasanfard et al., 2021). Despite the effectiveness of other factors in the improvement of a plant's growth, it could be predicted that the lentil genotypes that have the ability for faster emergence and establishment are more likely to be in a better position than other genotypes at other stages of development. A previous study has demonstrated that seed yields of both chickpea and dry pea in a semiarid environment can be enhanced by management practices that promote early seedling emergence, prolonged reproductive period, and increased pod fertility (Gan et al., 2002).

Days to 50% Flowering (D_{50f})

According to Table 3, there was a significant difference between the genotypes in terms of D_{50f}. In this regard, the lowest D_{50f} was related to the genotypes of MLC472, MLC286, and MLC11 while the highest level of the mentioned variable was observed in the genotypes of MLC38, MLC13, MLC47, and MLC70 (Table 3). Moreover, the range of D_{50f} varied from 66 to 75 days, and this diversity in the time of flowering was indicative of variety in the time of reaching the reproductive phase by lentil genotypes. Drought scape by lentil plants is possible with less D_{50f} or faster flowing in areas with a potential for drought stress. In this context, the plant completes its growth process before the onset of drought stress, which prevents yield reduction considering the sensitivity of lentil to drought stress, especially at the flowing stage (Barnabas et al., 2008; Sehgal et al., 2017). In other words, rapid flowing in areas affected by drought stress leads to the lack of interference of this stage with drought stress, which prevents fertility and fertilization reduction, thereby inhibiting yield decrease (Sehgal et al., 2019). The present study showed a negative, significant correlation (r=-0.53*) between D_{50f} and harvest index (HI) (Table 4). According to the results, the faster the flowering stage or less D_{50f}, resulted the higher the HI.

Plant Height

According to the results of the study, there was a significant difference between lentil genotypes in terms of plant height (Table 3). The results revealed that the highest plant height was related to the MLC47 genotype (44.7 cm), whereas the lowest height was observed in genotypes of MLC334, MLC472, MLC13, and MLC17 (Table 3).

Table 3. Comparison of mean, significance levels and coefficient of variation of phenological, morphological, yield and yield components of 15 lentil genotypes in field conditions

Traits	MLC 454	MLC 47	MLC 33	MLC 84	MLC 70	MLC11	MLC286	MLC472	MLC407	MLC38	MLC17	MLC469	MLC303	MLC334	MLC13	P value	CV (%)
Days to 50% emergence	29.7^{ab}	29.1^{bc}	31.1^{a}	29.0^{bc}	29.2^{bc}	28.4^{b-d}	25.4^{f}	26.6^{ef}	27.8^{c-e}	29.9^{ab}	29.2^{bc}	25.3^{f}	31.1^{a}	28.5^{b-d}	26.8^{d-f}	**	3.80
Days to 50% flowering	71.3^{c}	74.6^{a}	70.4^{c}	71.3^{c}	75.3^{a}	66.7^{d}	66.2^{d}	65.7^{d}	71.4^{c}	74.2^{ab}	70.6^{c}	72.2^{bc}	72.3^{bc}	71.3^{c}	74.6^{a}	**	1.80
Height (cm)	31.8^{de}	44.7^{a}	32.5^{de}	33.2^{de}	39.7^{b}	33.2^{de}	32.3^{de}	28.7^{gh}	36.2^{c}	31.7^{ef}	31.0^{e-g}	34.7^{cd}	32.0^{de}	27.2^{h}	28.8^{f-h}	**	5.10
Leaf length (cm)	4.10^{d-f}	3.60^{f-h}	6.60^{a}	6.40^{ab}	2.10^{i}	4.0^{d-f}	3.60^{f-h}	3.50^{f-h}	4.60^{cd}	3.20^{gh}	5.80^{b}	4.40^{c-e}	3.80^{e-g}	4.90^{c}	2.90^{h}	**	10.4
Leaflet length (cm)	1.10^{c}	1.40^{b}	1.50^{a}	0.60^{fg}	0.68^{ef}	1.20^{c}	0.67^{ef}	0.70^{de}	1.10^{c}	0.80^{d}	1.20^{c}	0.58^{fg}	0.66^{ef}	0.54^{g}	1.20^{c}	**	7.00
Leaflet width(cm)	0.29	0.31	0.25	0.32	0.23	0.30	0.28	0.25	0.38	0.26	0.32	0.22	0.25	0.29	0.27	ns	18.9
Flower length (cm)	0.51^{e-g}	0.60^{b-d}	0.61^{bc}	0.82^{a}	0.50^{gh}	0.51^{fg}	0.56^{c-e}	0.49^{gh}	0.62^{b}	0.45^{hi}	0.61^{bc}	0.42^{i}	0.61^{b}	0.43^{i}	0.56^{d-f}	**	4.70
Leaf area index (LAI)	1.80^{b}	1.30^{cd}	0.80^{ef}	0.80^{ef}	1.30^{cd}	1.10^{de}	0.70^{e-g}	0.90^{ef}	0.60^{f-h}	3.80^{a}	0.70^{e-g}	0.30^{h}	0.60^{f-h}	1.50^{bc}	0.40^{gh}	**	20.3
No. of branches ($plant^{-1}$)	3.10^{b-d}	4.40^{a}	2.70^{b-e}	2.40^{e}	3.10^{b-d}	2.50^{de}	2.90^{b-e}	3.10^{b-d}	2.70^{b-e}	3.10^{b-d}	2.90^{b-e}	3.30^{b}	3.20^{b}	2.50^{c-e}	2.30^{e}	**	12.9
First pod height (cm)	11.0^{a-d}	12.4^{a}	9.50^{b-f}	9.70^{a-f}	11.8^{ab}	10.2^{a-e}	7.60^{ef}	8.20^{ef}	10.3^{a-e}	10.1^{a-e}	7.10^{f}	8.70^{c-f}	8.30^{d-f}	11.1^{a-c}	8.40^{c-f}	*	17.1
Pod No. ($plant^{-1}$)	58.3	100	92.1	62.2	68.8	44.6	49.5	78.2	75.9	79.0	60.7	27.9	65.8	19.1	26.5	ns	47.7
Filled pod (%)	71.6^{ab}	43.7^{e}	79.4^{a}	75.2^{a}	73.1^{a}	75.9^{a}	61.9^{b-d}	72.3^{ab}	76.9^{a}	58.8^{cd}	57.0^{d}	68.6^{a-c}	36.2^{e}	76.2^{a}	75.5^{a}	**	9.90
100- seed weight (g)	4.0^{a}	2.40^{d}	3.60^{ab}	2.60^{d}	2.50^{d}	2.70^{d}	3.0^{cd}	3.0^{cd}	3.30^{bc}	2.70^{d}	2.50^{d}	2.60^{d}	3.92^{a}	2.40^{d}	3.0^{cd}	**	12.0
Biological yield ($g.m^{-2}$)	696^{a}	563^{b}	394^{c}	318^{d}	417^{c}	272^{ef}	256^{ef}	237^{fg}	253^{f}	430^{c}	295^{de}	198^{g}	242^{f}	147^{h}	118^{h}	**	7.40
Seed yield ($g.m^{-2}$)	134^{a}	125^{ab}	116^{b}	88.8^{c}	77.5^{cd}	72.5^{d}	66.0^{de}	57.5^{ef}	55.0^{ef}	50.5^{f}	47.5^{f}	25.3^{g}	16.0^{g}	13.8^{g}	11.5^{g}	**	13.2
Harvest Index (%)	19.2^{de}	22.3^{cd}	29.7^{a}	27.9^{ab}	18.6^{de}	26.7^{ab}	25.8^{a-c}	24.3^{bc}	21.9^{cd}	11.8^{g}	16.2^{ef}	12.9^{fg}	6.60^{h}	9.40^{gh}	9.90^{gh}	**	12.9

MLC: Mashhad Lentil Collection.

In each row, means with similar letters do not have a significant difference in the probability level of 0.05 based on the Duncan's Multiple Range Test (DMRT).

ns: no significant at probability level 5%, *: Significant at probability level 5%, **: Significant at probability level 1%

The difference between the highest and lowest plant heights in the genotypes evaluated was 17.5 cm, which demonstrated a significant difference between the genotypes in this regard. One of the most important limitations of mechanized harvesting of lentil is the low height of its plants. In fact, the existing machinery is unable to harvest short lentil plants, which will lead to manual harvesting and increased production costs.

As such, this limitation can be eliminated by choosing genotypes with high plant heights. Moreover, the lentil has indeterminate growth (Delahunty et al., 2018), and according to the positive, significant correlation observed in the present study (Table 4), an increase of plant height led to an increase in the height of the first pod from the soil surface (r=0.58*), increase in the number of branches (r=0.68*), and increase in the number of pods (r=0.52*), which raised the importance of plant height from the perspective of economic yield.

Leaf Length

According to Table 3, there was a significant difference between lentil genotypes in terms of leaf length, in a way that the highest leaf lengths (6.6 and 6.4 cm,) were observed in the genotypes of MLC33 and MLC84, respectively, and the lowest leaf length (2.1 cm) in the MLC70 genotype. The excessive increase in leaf length leads to possible shading and a higher respiration rate in dense cultivations, the excessive leaf length (taking into account other factors such as leaf area index) will reduce light loss by increasing the desired canopy formation rate (Barisic et al., 2006).

Length and Width of Leaflets

According to the results, there was a significant and insignificant difference between lentil genotypes in terms of the length and width of leaflets, respectively (Table 3). In this respect, the highest leaflet length (1.5 cm) was observed in the MLC33 genotype, compared to the other genotypes (Table 3). As mentioned above, the MLC33 genotype had the longest leaf length, compared to other genotypes. In addition, the positive, significant correlation (r=0.51*) between leaflet length and seed yield demonstrated that the former influenced on the latter (Table 4). In fact, seed yield increased with an increase in leaflet length. It is possible that by increasing the length of the leaflet or source, the production capacity of the grown material and its transfer to the reservoir will be done more favorably, which increase the seed yield (White et al., 2015).

Flower Length

According to the results, there was a significant difference between lentil genotypes in terms of flower length (Table 3). In this regard, the highest and lowest flower lengths were observed in genotypes of MLC84 (0.82 cm), and MLC469, MLC334 and MLC38 (0.42, 0.43, and 0.45), respectively (Table 3). Flower length ranged from 0.9 to 1.2 cm in a similar test on chickpea germplasm collections (Nezami et al., 2010).

Table 4. Correlation coefficients of phenological, morphological, yield and yield components of 15 lentil genotypes used in this study in the field condition.

	Traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Days to 50% emergence	1															
2	Days to 50% flowering	0.35^{ns}	1														
3	Height	0.12^{ns}	0.42^{ns}	1													
4	Leaf length	0.27^{ns}	-0.26^{ns}	-0.21^{ns}	1												
5	Leaflet length	0.37^{ns}	0.09^{ns}	0.27^{ns}	0.20^{ns}	1											
6	Leaflet width	0.12^{ns}	-0.12^{ns}	0.05^{ns}	0.46^{ns}	0.28^{ns}	1										
7	Flower length	0.22^{ns}	0.08^{ns}	0.15^{ns}	0.47^{ns}	0.15^{ns}	0.49^{ns}	1									
8	Leaf area index	0.39^{ns}	0.26^{ns}	-0.01^{ns}	-0.27^{ns}	-0.06^{ns}	-0.10^{ns}	-0.40^{ns}	1								
9	No. of branches	0.10^{ns}	0.28^{ns}	0.68^{**}	-0.30^{ns}	0.16^{ns}	-0.19^{ns}	-0.17^{ns}	0.16^{ns}	1							
10	First pod height	0.38^{ns}	0.46^{ns}	0.58^{*}	-0.21^{ns}	0.14^{ns}	0.09^{ns}	-0.17^{ns}	0.42^{ns}	0.32^{ns}	1						
11	Pod No.	0.50^{ns}	0.10^{ns}	0.52^{*}	0.06^{ns}	0.44^{ns}	0.16^{ns}	0.31^{ns}	0.26^{ns}	0.54^{*}	0.26^{ns}	1					
12	Filled pod %	-0.26^{ns}	-0.24^{ns}	-0.30^{ns}	023^{ns}	0.02^{ns}	0.13^{ns}	-0.10^{ns}	-0.12^{ns}	-0.68^{**}	0.11^{ns}	-0.30^{ns}	1				
13	100-seed weight	0.16^{ns}	-0.12^{ns}	-0.26^{ns}	0.14^{ns}	0.26^{ns}	0.30^{ns}	0.15^{ns}	-0.31^{ns}	-0.12^{ns}	-0.26^{ns}	0.03^{ns}	-0.02^{ns}	1			
14	Biological yield	0.50^{ns}	0.26^{ns}	0.50^{ns}	-0.06^{ns}	0.40^{ns}	0.03^{ns}	-0.01^{ns}	0.50^{ns}	0.52^{*}	0.57^{*}	0.59^{*}	-0.19^{ns}	0.16^{ns}	1		
15	Seed yield	0.37^{ns}	-0.04^{ns}	0.51^{ns}	0.19^{ns}	0.51^{*}	0.14^{ns}	0.21^{ns}	0.19^{ns}	0.35^{ns}	0.49^{ns}	0.63^{*}	0.08^{ns}	0.13^{ns}	0.86^{**}	1	
16	Harvest Index	-0.02^{ns}	-0.53^{*}	0.28^{ns}	0.37^{ns}	0.33^{ns}	0.25^{ns}	0.36^{ns}	-0.17^{ns}	-0.04^{ns}	0.09^{ns}	0.47^{ns}	0.38^{ns}	-0.03^{ns}	0.29^{ns}	0.72^{**}	1

ns: no significant at probability level 5%, *: Significant at probability level 5%, **: Significant at probability level 1%

Leaf Area Index (LAI)

According to the results, a significant difference was found between lentil genotypes in terms of leaf area index (LAI) (Table 3). In this respect, the highest LAI (3.8) was observed in the MLC38 genotype, whereas the lowest LAI (0.3, 0.4, 0.6, and 0.6) was reported in genotypes of MLC469, MLC13, MLC303, and MLC407, respectively) (Table 3). The MLC38 genotype had more light absorption capacity and ultimately higher photosynthesis level.

The Number of Branches per Plant

In this study, there was a significant difference between the genotypes assessed in terms of the number of branches per plant (Table 3). In this regard, about 55% of the genotypes had 2.3-2.9 branches per plant on average (Table 3). Meanwhile, the MLC47 genotype had 4.4 branches per plant, which showed the highest branch production ability of the genotype, compared to the other genotypes. In a similar study on 12 lentil genotypes, the number of branches per plant was reported in the range of 4.25-6.25 (Colkesen et al., 2014). As mentioned before, the MLC47 genotype had the highest height among the samples, which justified the higher number of branches per plant in this genotype. Overall, an increased number of branches is a positive factor for the selection of legumes such as lentil, and the positive, significant correlation (r=0.54*) with the number of pods is indicative of the significant importance of branching in lentil. Moreover, the changes in branching were in line with changes in the biological yield of the product in the current study (r=0.52*). In other words, increased branching along with a higher biological yield of lentil can be recognized as an important factor for the selection of genotypes.

First Pod Height (FPH)

There was a significant difference between the genotypes in terms of the first pod height (FPH) from the soil surface (Table 3). The FPH of 55% of the genotypes was more than 10 cm. However, the highest FPH (12.4 cm) was related to the MLC47 genotype, compared to the other types (Table 3), which could create a suitable condition for mechanized harvesting of the product. In this context, researchers reported the FPH of 14.5-22.2 cm (Colkesen et al., 2014), 5.6-14.2 cm (Gupta et al., 2012), and 8-24 cm (Kayan et al., 2008) for lentil genotypes. The current test demonstrated a positive, significant correlation between FPH (r=0.58*) and biological yield (r=0.57*). In a similar test by Karadavut (2009), the results were indicative of a positive, significant correlation between FPH and plant height in lentil cultivars (r=0.52*). Therefore, selecting genotypes with a higher FPH would significantly reduce harvest costs in case of an acceptable yield.

Number of Pods and Percentage of Fertile Pods

According to the results, there was a nonsignificant and significant difference between the genotypes in terms of the number of pods and the percentage of fertile pods, respectively (Table 3). In this regard, the highest percentage of fertile pods (79.4%) was observed in the MLC33 genotype. However, no significant difference was observed between the mentioned genotype and 60% of all genotypes (Table 3). This showed high fertility in a wide range of genotypes assessed. Moreover, the highest number of infertile pods (empty pods) was observed in genotypes of MLC303 and MLC47 (36.2% and 43.7%, respectively). According to the results, there was a negative, significant correlation between fertile pods and the number of branches per plant (r=-0.68*), which demonstrated that more branching leads to the allocation of less photosynthetic material from the source to seeds. As mentioned above, the MLC47 genotype had the highest branching ability while a low percentage of fertile pods was detected in this genotype. Therefore, by producing more branches or pods, the source is likely to face a limited supply of nutrients for each of the vegetative and reproductive organs (Smith et al., 2018). As such, concerning the importance of more branching in legumes (e.g., lentil), a genotype can be selected if it has the ability of more branching and producing more fertile pods.

100-Seed Weight

A significant difference was observed between the genotypes in terms of 100-seed weight (Table 3), in a way that the highest 100-seed weight (4.0, 3.9, and 3.6 gr) was observed in MLC454, MLC303, and MLC33 genotypes, respectively. On the other hand, the lowest 100-seed weight (2.4-3.0 gr) was observed in 60% of the genotypes assessed (Table 3). A higher 100-seed weight is one of the most important components of plant yield, which is an important factor in the capacity of the sink to receive photosynthetic material in the plant. Therefore, the source-sink relationship is extremely important in seed weight during the filling of the seeds (Ballesteros-Rodriguez et al., 2019). Given the lack of non-biological stresses (e.g., drought stress) at the time of grain filling and equal conditions for all genotypes, the significant difference in the 100-seed weight of genotypes might be related to their type. In a similar test, the 100-seed weight of lentil was reported in the range of 2.8-6.1 gr, which demonstrated a difference between the samples evaluated in this regard (Akdeniz et al., 2019).

Biological Yield

In this research, a significant difference between lentil genotypes regarding the biological yield was observed (Table 3). The difference between the highest and lowest biological yield in genotypes was 578 g m^{-2}, which showed a significant difference in the biomass of the genotypes. In this regard, the highest biological yield (696 g m^{-2}) was observed in the MLC454 genotype, whereas the lowest biological yield (118 and 147 g m^{-2}) was related to the genotypes of MLC13 and MLC334,, respectively) (Table 3). According to Table 4, there was a positive, significant correlation between biological yield and the number of pods (r=0.59*).

Seed Yield

In this study, there was a significant difference between lentil genotypes in terms of seed yield (Table 3). In

addition, the difference between the highest and lowest seed yield was 122 g m^{-2}, which demonstrated a high difference in this trait (Table 3). The highest level of seed yield (133.8 and 125 g m^{-2}) was observed in genotypes of MLC454 and MLC47, respectively, while the lowest level of seed yield (11.5, 13.8, 16, and 25.3 g m^{-2}) was related to the genotypes of MLC13, MLC334, MLC303, and MLC469, respectively (Table 3). Moreover, the positive, significant correlation between biological and seed yield (r=0.86**) was observed (Table 4) which demonstrated that the changes in seed yield and biological yield are in line with each other. A similar test reported a positive, significant correlation (r=0.83**) between seed and biological yield in lentil cultivars (Karadavut, 2009). Therefore, since one of the most important factors for lentil selection is seed yield. It is vital to select genotypes with high seed yield, especially in unfavorable environmental situations.

Harvest Index (HI)

There was a significant difference between lentil genotypes in terms of HI (Table 1). In this regard, the highest HI (29.7%, 27.9%, 26.7%, and 25.8%) was observed in genotypes of MLC33, MLC84, MLC11, and MLC286, respectively, whereas the lowest HI (6.6%, 9.4%, and 9.9%) was related to genotypes of MLC303, MLC334, and MLC13, respectively (Table 3). Some studies have reported the HI range of lentil to be 6-51% (Unkovich et al., 2010), which is likely to change under the influence of environmental stress conditions. The higher HI in the four superior genotypes is indicative of their greater ability to allocate more photosynthetic material to seeds, which is an important factor in the superiority of a genotype over other genotypes (Sandana and Calderini, 2019). In other words, the distribution of nutrients to the plant's economic sector is the distinguishing feature of a superior genotype from that of other genotypes. According to Table 4, there was a positive, significant correlation between HI and seed yield (r=0.72**). In this regard, Karadavut (2009) also found a positive, significant correlation between HI and lentil's seed yield (r=0.69**). Therefore, the increase in seed yield plays a vital role in the increase of HI. In other words, genotypes with a higher HI have a lower sink limitation and a greater ability to receive photosynthetic material in seeds. On the other hand, a low HI in genotypes shows that most of the photosynthetic material remains in the vegetative structure of the plant, which is probably due to sink limitation to receive cultivated materials.

Genotype Grouping

In this research, cluster analysis was applied for the lentil genotype group (Fig. 2). Thus, the genotypes tested were divided into four groups, according to which six genotypes were classified in the first group, two genotypes in the second group, four genotypes in the third group, and three genotypes in the fourth group (Fig. 2). According to Table 5, the comparison of the mean of each group with the total mean showed that the mean branch number and plant height were higher in the fourth group. On the other hand, the fertility percentage of full pod percentage was higher in the first and second groups, compared to the total mean.

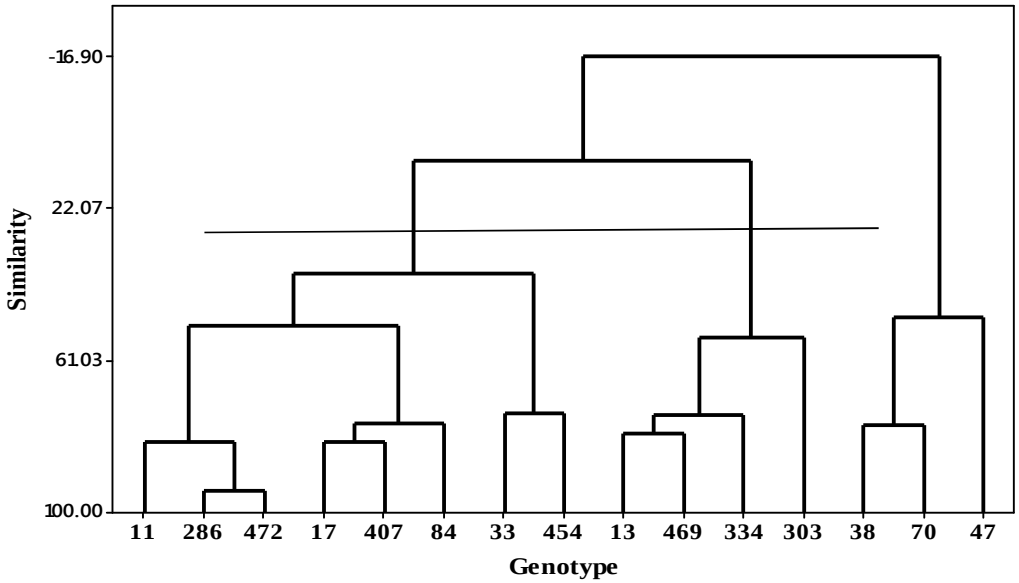

Fig. 2. Dendrogram of 15 lentil genotypes revealed by WARD cluster analysis based on Jaccard's similarity coefficients.

Table 5. Mean and deviation from mean of groups in cluster analysis for traits in Lentil genotypes in field conditions

Lentil genotypes	Groups							
	1		2		3		4	
	MLC11, MLC17, MLC286, MLC407, MLC472, MLC84		MLC33, MLC454		MLC13, MLC334, MLC469, MLC303		MLC38, MLC70, MLC47	
Traits	Group mean	DFM	Group mean	DFM	Group mean	DFM	Group mean	DFM
Days to 50% emergence	27.7	-0.8	30.5	2.0	27.9	-0.6	29.4	0.9
Days to 50% flowering	68.7	-2.5	70.8	-0.4	72.5	1.3	74.7	3.5
Height (cm)	32.6	-0.7	32.3	-1.0	30.8	-2.5	38.7	5.4
Leaf length (cm)	4.7	0.5	5.3	1.1	4.0	-0.2	2.9	-1.3
Leaflet length(cm)	0.9	0.0	1.3	0.4	0.8	-0.1	1.0	0.1
Leaflet width(cm)	0.32	0.03	0.28	-0.01	0.27	-0.02	0.27	-0.02
Flower length (cm)	0.6	0.0	0.6	0.0	0.5	-0.1	0.5	-0.1
Leaf area index	0.8	-0.3	1.3	0.2	0.7	-0.4	2.2	1.1
No. of branches ($plant^{-1}$)	2.8	-0.1	2.9	0.0	2.8	-0.1	3.5	0.6
Lowest pod height (cm)	8.8	-0.8	10.3	0.7	9.1	-0.5	11.4	1.8
Pod No. ($plant^{-1}$)	61.8	1.2	75.2	14.6	34.8	-25.8	82.7	22.1
Filled pod (%)	69.8	3.0	75.3	8.5	64	-2.8	58.6	-8.2
100- seed weight (g)	2.9	-0.1	4.0	1.0	3.2	0.2	2.3	-0.7
Biological yield ($g.m^{-2}$)	272	-50.6	545	223	176	-146	470	148
Seed yield ($g.m^{-2}$)	64.7	0.9	125	61.2	16.6	-47.2	84.3	20.5
Harvest Index (%)	23.9	4.9	24.5	5.5	9.8	-9.2	17.6	-1.4

Abbreviation: MLC: Mashhad lentil collection; DFM: Deviation from mean

CONCLUSION

According to the results of the present study, the genotypes in the second group (MLC33 and MLC454) had a higher mean in 69% of the traits evaluated, However, if the main criteria for selection is considered to be the higher height of genotypes for mechanical harvesting, the genotypes MLC38, MLC70, and MLC47 which located in the fourth group of genotype grouping (Fig. 2) will be proper choices. Moreover, the mean seed yield was higher in the first, second and fourth groups, compared to the total mean, which demonstrated the favorable potential of these genotypes considering the importance of the economic part of the issue. In addition, while the mean HI was higher in the first and second groups, compared to the total mean, it was lower in the other groups.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Akdeniz, H., Koc, A., Hosafliglu, I., Hossain, A., Islam, M. S., Hafez, E., & El Sabagh, A. (2019). Evaluation of phenology, growth, yiled and technological characteristics of some winter green lentil (*Lens culinaris* Medic.) genotypes grown under mediterranean environment. *Fresenius Environmental Bulletin*, 28(7), 5430-5434.

Alemu, B., Lule, D., Tesfaye, K., & Haileselassie, T. (2018). Interrelationships of quantitative traits and genetic variability of Desi type chickpea genotypes as revealed by agro-morphology and inter simple sequence repeat markers. *African Journal of Biotechnology*, 17(21), 685-693.

Ballesteros-Rodríguez, E., Martínez-Rueda, C. G., Morales-Rosales, E. J., Estrada-Campuzano, G., & González, G. F. (2019). Changes in number and weight of wheat and triticale grains to manipulation in source-sink relationship. *International Journal of Agronomy*, 2019, 1-9.

Barisic, N., Stojković, B., & Tarasjev, A. (2006). Plastic responses to light intensity and planting density in three *Lamium* species. *Plant Systematics and Evolution*, 262(1-2), 25-36.

Barnabas, B., Jager, K., & Feher, A. (2008). The effect of drought and heat stress on reproductive processes in cereals. *Plant, Cell and Environment*, 31(1), 11-38.

Colkesen, M., Idikut, L., Zulkadir, G., Cokkizgin, A., Girgel, U., & Boylu, O. A. (2014). Determination of yield and yield components of various winter lentil genotypes (*Lens culinaris* Medic.) in kahramanmaras conditions. *Turkish Journal of Agricultural and Natural Sciences* (*Turk Tarım ve Doga Bilimleri Dergisi*,), Special Issue: 1, 2014, 1247-1253.

Delahunty, A., Nuttall, J., Nicolas, M., & Brand, J. (2018). Response of lentil to high temperature under variable water supply and carbon dioxide enrichment. *Crop and Pasture Science*, 69(11), 1103-1112.

Erskine, W., Diekmann, J., Jegatheeswaran, P., Salkini, A., Saxena, M. C., Ghanaim, A., & El Ashkar, F. (1991). Evaluation of lentil harvest systems for different sowing methods and cultivars in Syria. *The Journal of Agricultural Science*, 117(3), 333-338.

Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), (2019). Food and Agriculture Organization of the United Nations. http:// www. fao.org/faostat/en/#compare (Accessed: 14 December 2019).

Gaad, D., laouar, M., abdelguerfi, A., & gaboun, F. (2018). Collection and agro morphological characterization of Algerian accessions of lentil (*Lens culinaris*). *Biodiversitas Journal of Biological Diversity*, 19(1), 183-193.

Gan, Y. T., Miller, P. R., Liu, P. H., Stevenson, F. C., & McDonald, C. L. (2002). Seedling emergence, pod development, and seed yields of chickpea and dry pea in a semiarid environment. *Canadian Journal of Plant Science*, 82(3), 531-537.

Giannakoula, A. E., Ilias, I. F., Maksimovic, J. J. D., Maksimović, V. M., & Zivanović, B. D. (2012). The effects of plant growth regulators on growth, yield, and phenolic profile of lentil plants. *Journal of Food Composition and Analysis*, 28(1), 46-53.

Gupta, R., Begum, S. N., Islam, M. M., & Alam, M. S. (2012). Characterization of lentil (*Lens culinaris* M.) germplasm through phenotypic marker. *Journal of the Bangladesh Agricultural University*, 10(2), 197-204.

Hall, C., Dawson, T. P., Macdiarmid, J. I., Matthews, R. B., & Smith, P. (2017). The impact of population growth and climate change on food security in Africa: Looking ahead to 2050. *International Journal of Agricultural Sustainability*, 15(2), 124-135.

Hasanfard, A., Rastgoo, M., Darbandi, E. I., Nezami, A., & Chauhan, B. S. (2021). Regeneration capacity after exposure to freezing in wild oat (*Avena ludoviciana* Durieu.) and turnipweed (*Rapistrum rugosum* (L.) All.) in comparison with winter wheat. *Environmental and Experimental Botany*, 181, 1-8.

Karadavut, U. (2009). Path analysis for yield and yield components in lentil (*Lens culinaris* Medik.). *Turkish Journal of Field Crops*, 14(2), 97-104.

Ministry of Jihad-e-Agriculture Iran. (2017). Iran Agriculture Statistics. Volume I: Crops Retrieved from https://agri-es.ir/Default.aspx?tabid=1925

Kayan, N. (2008). Variation for yield components in two winter sown lentil cultivars (*Lens culinaris* Medic.). *Bulgarian Journal of Agricultural Science*, 14(5), 460-465.

Nabati, J., Nezami, A., Mirmiran, S. M., Hasanfard, A., Hojjat, S. S., & Bagheri, A. R. (2020). Freezing tolerance in some lentil genotypes under controlled conditions. *Seed and Plant Journal*, 36(2), 183-205.

Nezami, A., Pouramir, F., Momeni, S., Porsa, H., Ganjeali, A., & Bagheri, A. (2010). Evaluation of phenologic, morphologic and yield characteristics of chickpea germplasms in Ferdowsi University of Mashhad Seed Bank I. Deci type chickpeas. *Iranian Journal of Pulses Research*. 1(2), 21-36.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., Lobell, D. B., & Travasso, M. I. (2014). Chapter 7: Food security and food production systems. In: Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R., White, L. L. (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on climate change*. (pp. 485–533) Cambridge, United Kingdom, and New York, NY, USA: Cambridge University Press.

Sandana, P., & Calderini, D. F. (2019). *Crop Science. Source-sink relationships in cereals and legumes*. New York, NY: Springer.

Sarker, A., & Kumar, S. (2011). Lentils in production and food systems in west Asia and Africa. *Grain Legumes*. 57, 46-48.

Sarker, A., Rizvi, A. H., & Singh, M. (2018). Genetic variability for nutritional quality in lentil (*Lens culinaris* Medikus subsp. *culinaris*). *Legume Research-An International Journal*, 41(3), 363-368.

Sehgal, A., Sita, K., Bhandari, K., Kumar, S., Kumar, J., Vara Prasad, P. V., Siddique, K. H. M., and Nayyar, H. (2019). Influence of drought and heat stress, applied independently or in combination during seed development, on qualitative and quantitative aspects of seeds of lentil (*Lens culinaris* Medikus) genotypes, differing in drought sensitivity. *Plant, Cell and Environment*, 42(1), 198-211.

Sehgal, A., Sita, K., Kumar, J., Kumar, S., Singh, S., Siddique, K. H., & Nayyar, H. (2017). Effects of drought, heat and their interaction on the growth, yield and photosynthetic function of lentil (*Lens culinaris* Medikus) genotypes varying in heat and drought sensitivity. *Frontiers in Plant Science*, 8, 1776.

Smith, M. R., Rao, I. M., & Merchant, A. (2018). Source-sink relationships in crop plants and their influence on yield development and nutritional quality. *Frontiers in Plant Science*, 9, 1-10.

Smykal, P., Coyne, C. J., Ambrose, M. J., Maxted, N., Schaefer, H., Blair, M. W., Berger, J., Greene, S. L., Nelson, M. N., Besharat, N., Vymyslicky, T., Toker, C., Saxena, R. K., Roorkiwal, M., Pandey, M. K., Hu, J., Li, Y. H., Wang, L. X., Guo, Y., Qiu, L. J., Redden, R. J., & Varshney, R. K. (2015). Legume crops phylogeny and genetic diversity for science and breeding. *Critical Reviews in Plant Sciences*, 34(1-3), 43-104.

Toklu, F., Biçer, B., & Karaköy, T. (2009). Agro-morphological characterization of the Turkish lentil landraces. *African Journal of Biotechnology*, 8(17), 4121-4127.

Tsanakas, G. F., Mylona, P. V., Koura, K., Gleridou, A., & Polidoros, A. N. (2018). Genetic diversity analysis of the Greek lentil (*Lens culinaris*) landrace 'Eglouvis' using morphological and molecular markers. *Plant Genetic Resources*, 16(5), 469-477.

Unkovich, M., Baldock, J., & Forbes, M. (2010). *Variability in harvest index of grain crops and potential significance for carbon accounting: Examples from Australian agriculture*. *In Advances in Agronomy*. Cambridge: Academic Press.

Upadhyaya, H. D., Ortiz, R., Bramel, P. J., & Singh, S. (2002). Phenotypic diversity for morphological and agronomic characteristics in chickpea core collection. *Euphytica*, 123(3), 333-342.

Wanare, S. W. (2015). *Stability analysis in chickpea (Cicer arietinum L.)* (Doctoral dissertation, MPKY, University library).

White, A. C., Rogers, A., Rees, M., & Osborne, C. P. (2015). How can we make plants grow faster? A source–sink perspective on growth rate. *Journal of Experimental Botany*, 67(1), 31-45.

تحقیقات کشاورزی ایران (۱۴۰۰) ۴۰(۱)۵۱-۶۰

مقاله علمی- پژوهشی

به‌گزینی ژنوتیپ‌های عدس (*Lens culinaris* medik.) از طریق ارزیابی خصوصیات فنولوژیکی، مورفولوژیکی، عملکرد و اجزای عملکرد

جعفر نباتی[1*]، احمد نظامی[1,2]، علیرضا حسن‌فرد[2]، محمد زارع مهرجرد[3]، مهدی راستگو[2]

[1]گروه پژوهشی بقولات، پژوهشکده علوم گیاهی، دانشگاه فردوسی مشهد، مشهد، ج. ا. ایران
[2]گروه اگروتکنولوژی، دانشکده کشاورزی، دانشگاه فردوسی مشهد، مشهد، ج. ا. ایران
[3]مجتمع آموزش عالی شیروان، شیروان، ج. ا. ایران

*نویسنده مسئول

اطلاعات مقاله

تاریخچه مقاله:
تاریخ دریافت: ۱۳۹۹/۱۰/۲۴
تاریخ پذیرش: ۱۴۰۰/۳/۲۴
تاریخ دسترسی: ۱۴۰۰/۰۵/۲۰

واژه‌های کلیدی:
غلاف بارور
منابع ژنتیکی
ژرم‌پلاسم داخلی
عملکرد دانه

چکیده- بهره‌مندی از منابع ژنتیکی عدس جهت به‌گزینی آن‌ها در زمینهٔ عملکرد اقتصادی بیشتر و بهره‌گیری از حداکثر پتانسیل تولید از طریق جایگزینی تعداد محدودی از ارقام اصلاح شده با ژرم‌پلاسم بومی امری ضروری است. به همین منظور مطالعهٔ حاضر در اواسط بهمن‌ماه ۱۳۹۷ در راستای ارزیابی خصوصیات فنولوژیک، مورفولوژیک، عملکرد و اجزای عملکرد ۱۵ ژنوتیپ عدس در مزرعهٔ تحقیقاتی دانشکده کشاورزی دانشگاه فردوسی مشهد در قالب طرح بلوک‌های کامل تصادفی با سه تکرار انجام شد. نتایج نشان داد که ژنوتیپ MLC47 با ارتفاع ۴۴/۷ سانتی‌متر و تعداد ۴/۴ شاخه در بوته در مقایسه با سایر ژنوتیپ‌ها برتر بود. ژنوتیپ MLC33 با باروری ۷۹/۴ درصد بیش‌ترین غلاف بارور را داشت و ۶۰ درصد از ژنوتیپ‌ها به‌لحاظ آماری با این ژنوتیپ در این صفت تفاوت معنی‌داری نداشتند. همچنین ژنوتیپ‌های MLC454 و MLC47 به ترتیب با ۱۳۳/۸ و ۱۲۵ گرم دانه در بوته بیش‌ترین عملکرد دانه را داشتند. گروه‌بندی خوشه‌ای و مقایسه میانگین گروه‌ها با میانگین کل نشان داد که ژنوتیپ‌های MLC33 و MLC454 در ۶۹ درصد از صفات مورد بررسی، میانگین بیشتری نسبت به سایر ژنوتیپ‌ها داشتند که می‌توانند در برنامه‌های تحقیقاتی آتی برای شناسایی و به‌گزینی ژنوتیپ‌های برتر عدس مورد استفاده قرار گیرند.