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Evaluation of Advanced Lentil Lines for Diversity in Seed Mineral Concentration, Grain Yield and Yield Components

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ABSTRACT

Lentil is one of the most important grain legumes, which plays a significant role in human nutrition and animal feed through the world. In developing countries, the prohibitively high cost of meat has rendered, lentil, with its high seed protein and essential amino acid content, important source of dietary protein. In this research, 181 lentil advanced lines (F_7 generation) of Karacadağ x Silvan and Karacadağ x Çağıl 2004 crosses were evaluated for grain yield, yield components and seed mineral concentrations in two diverse environments in Turkey. Considerable diversity was observed with regard to yield components and seed mineral concentrations in the advanced lentil lines. The greatest phenotypic diversity was observed in the biological yield, number of pods and weight of pods per plant, the number of seeds and weight of seeds per plant, and seed Ca, Zn and Fe concentrations. Grain yield per plant was significantly positively correlated with the biological yield per plant, number of pods per plant, weight of pods per plant, and number of seeds per plant. Plant grain yield and yield components were strongly positively correlated with seed potassium (K), calcium (Ca), magnesium (Mg) and zinc (Zn) concentrations but was negatively correlated with Fe concentration. In conclusion, promising lentil advanced lines for the grain yield, yield components and mineral concentrations could be evaluated for developing new lentil varieties and spesific breeding purposes.

Keywords: Lentil; Crosses; Mineral concentration; Yield components; Diversity

İleri Kademedeki Mercimek Hatlarının Dane Mineral Madde Konsantrasyonu, Verim ve Verim Komponentleri Yönünden Değerlendirilmesi

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ÖZET

Mercimek, insan ve hayvan beslenmesi yönünden yemeklik dane baklagiller grubunun en önemli üyelerinden birisidir. Gelişmekte olan ülkelerde et fiyatının yüksek olması; yüksek protein içeriği ve amino asit kompozisyonu ile mercimeği protein kaynağı olarak ön plana çıkarmaktadır. Bu araştırmada, Karacadağ x Silvan ve Karacadağ x Çağıl 2004 mercimek melez kombinasyonlarına ilişkin ileri kademedeki (F_7) 181 adet mecimek hattı iki farklı lokasyonda yetiştirilerek, dane verimi, verim komponentleri ve danede mineral madde konsantrasyonu yönünden incelenmiştir. Verim komponentleri ve mineral madde konsantrasyonu yönünden ileri kademedeki mercimek hatları arasında önemli düzeyde varyasyonlar saptanmıştır. Biyolojik verim, bitkide bakla sayısı, bitkide bakla ağırlığı, bitkide tohum sayısı, bitki dane verimi, tohumda kalsiyum (Ca), çinko (Zn) ve demir (Fe) konsantrasyonu yönünden önemli varyasyonlar tespit edilmiştir. Bitki dane verimi ile biyolojik verim, bitkide bakla sayısı, bitkide bakla ağırlığı ve bitkide dane sayısı arasında önemli pozitif ilişkiler belirlenmiştir. Dane verimi ve verim komponentlerinin danede potasyum (K), kalsiyum (Ca), magnezyum (Mg) ve çinko (Zn) konsantrasyonları ile pozitif, demir (Fe) konsantrasyonu ile negatif ilişkili olduğu saptanmıştır. Sonuç olarak, incelenen kırmızı mercimek ileri melez hatları içerisinde dane verimi, verim komponentleri ve mineral madde konsantrasyonu yönünden ümitvar olanların, gelecekte çeşit adayı olabileceği ve ıslah çalışmalarında spesifik amaçlar için kullanılabileceği tespit edilmiştir.

Anahtar Kelimeler: Mercimek; Melezleme; Mineral içeriği; Verim komponentleri; Çeşitlilik

1. Introduction

Lentil (*Lens culinaris* Medik) is a diploid (2n= 2x= 14), self-pollinated (autogamous) and annual species of grain legume and is considered to be one of the most ancient crops, as researchers have traced it back to 7,000-8,000 BC (Cubero 1981; Lev-Yadun et al 2000). Building and improving an effective lentil breeding program, requires utilizing lentil genetic resources effectively and efficiently in order to develop valuable genotypic and phenotypic variations in promising new varieties (Gepts 2006; Singh et al 2014). In light of this, this research developed a utilization program comprised of lentil landraces of considerable plant trait diversity (Toklu et al 2009a, b) and, in the F_7 generation, assessed advanced lines of two cross combinations. Lentil is a major source of protein, minerals and vitamins in human diet (Khan 1987; Iqbal et al 2006; Karaköy et al 2012). In addition, its mineral- and carbohydrate-rich straw provides valuable animal fodder (Muehlbauer et al 2006). Pulses play an important role in the nutrition of low-income people in many developing countries, as they are high in protein, minerals, vitamins, calories, dietary fiber and carboydrate (Solanki et al 1999; Iqbal et al 2006; Upadhyaya et al 2011; Blair 2013). Several reports have shown that two-thirds of the world's population faces deficiencies of essential minerals and vitamins (WHO 1999; Welch & Graham 2004; White & Broadley 2009). It has been reported that approximately 170 million pre-school-aged children in developing countries are not getting enough protein (Iqbal et al 2006). Fe, Zn, Cu, Ca, Mg, I and Se are the most commonly lacking minerals in the human diet (White & Broadley 2009). Several researchers have reported that mineral malnutrition affects more than half of the world's population particularly in developing countries (Mayer et al 2008), and this problem could be solved through increased consumption of mineral-rich foods enhanced using biofortification (White & Broadley 2005; 2009; Shahzad et al 2014). In this context, biofortification is defined as the enrichment of the edible portion of plants containing micronutrients through agronomic intervention or plant breeding (Welch & Graham 2004; White & Broadley 2005). Limited research has been done on grain quality, as research on lentil has thus far primarily focused on grain yield and yield related traits. The utilization of plant genetic resources is one of the most effective ways to increase grain yield and quality in lentil. Identifying genotypes that produce high mineral concentrations and promising plant traits and using these genetic resources in breeding programs are the keys to successful crop improvement (White & Broadley 2005; Roy et al 2013). Therefore, this study was undertaken with a focus on mineral concentrations and promising plant traits, and to identify superior advanced lines for future breeding purposes including biofortification, grain yield and yield components.

2. Material and Methods

2.1. Growth conditions and research materials

This research was conducted in two diverse environments: the Kozan Vocational School of Çukurova University, located in Kozan, Adana, Turkey, and the Sivas Vocational School of Cumhuriyet University located in Sivas, Turkey. The two locations have diverse soil and climatic conditions (Table 1); the soil at the Sivas location is silty clay with a pH of 7.28, 0.33 mmhos cm^{-1} salt, and 344, 560, 3.99, 0.42, 4.68 and 1.23 mg kg^{-1} K, Mg, Fe, Zn, Mn and Cu, respectively. The Kozan location is clay with a pH of 7.50, 0.20 mmhos cm^{-1} salt, and 252, 490, 4.30, 0.70, 8.90 and 0.70 mg kg^{-1} K, Mg, Fe, Zn, Mn and Cu, respectively. The research material consisted of RILs (recombinant inbred lines) derived from Karacadağ x Silvan cross with single seed descent (127 RILs in the F_7 generation) and Karacadağ x Çağıl 2004 cross (54 RILs in the F_7 generation) red lentil landraces and four check varieties (Şakar, Fırat 87, Kırmızı 51 and Kafkas). The experiments were arranged in an Augmented Block Design at both locations; the seeds of the parental genotypes, RILs and check varieties were sown by hand in 1-m-long rows with 20-cm row spacing and a 5-cm plant diameter. Seeds were sown in December 20, 2013 and harvested in June 5, 2014 at the Kozan location under rainfed conditions and, sown in April 25, 2014 at the Sivas location under irrigated conditions and harvested in August 15, 2014.

Table 1- Geographical, soil and climatic specifications of the experimental sites

Çizelge 1- Denemelerin yürütüldüğü loksyonların coğrafi, toprak ve iklim yapısına ilişkin bazı veriler

Features	*Sivas*	*Kozan/ Adana*
*Meteorological features**	*(April-August)*	*(November-May)*
Total rainfall (mm)	119.5	620.8
Mean temperature (^{o}C)	18.1	14.3
Mean humidity (%)	52.2	58.9
Altitude (m)	1250	110
*Soil features***		
Soil texture	Silty-clay	Clay
pH	7.28	7.50
Salt (mmhos cm^{-1})	0.33	0.20
$CaCO_3$ (%)	19.6	27
K (mg kg^{-1})	344	252
Mg (mg kg^{-1})	560	490
Fe (mg kg^{-1})	3.99	4.30
Zn (mg kg^{-1})	0.42	0.70
Mn (mg kg^{-1})	4.68	8.90
Cu (mg kg^{-1})	1.23	0.70

*, meteorological data provided by Turkish State Meteorological Service; **, soil features provided by Cumhuriyet University and Çukurova University soil analysis laboratories

2.2. Determination of agromorphological traits

The traits of days to 50% flowering (DF) (days from sowing to appearance of 50% flowers), biological yield (recorded mean above-ground weight of each plant as g per plant), plant height (cm), the number of branches per plant, the number of pods per plant, the weight of pods per plant, the number of seeds per plant, and the 1000 seed weight and the weight of seeds per plant were identified from five randomly selected plants in each row.

2.3. Seed mineral concentration analysis

For the mineral nutrient analysis, 0.3 g seed samples of each of the lentil genotypes were ground and then decomposed in a microwave digester using 2 mL of 35% H_2O_2 and 5 mL of 65% HNO_3 (Alcock 1987). Following the digestion, K, Ca, Mg, Zn, Fe, Cu and Mn were analyzed by using an inductively coupled plasma optical emission spectrometer (ICP-OES; Varian-Vista Pro). Reference leaf samples from the National Institute of Standards and Technology (Gaithersburg, MD, USA) were used to check the related elemental measurements.

Simple statistics, including the mean, range (minimum and maximum) and the coefficient of variation, were computed using the mean values for each plant characteristic using Microsoft Office Excel. The correlation coefficients were calculated by using JMP statistical software (SAS 2007).

3. Results and Discussion

Large phenotypic variation was detected in the advanced lentil lines for the agromorphological plant characteristics and seed mineral concentrations in both environments when compared to the check varieties (Table 2 and 3). For the lentil advanced lines, days to 50% flowering ranged from 106 to 110 days with a mean of 107.6 days at Kozan and ranged from 54 to 66 days with a mean of 57.6 days at Sivas. A greater number of days to 50% flowering was observed in Kozan in comparison to Sivas, depending on the growing period. Plants were grown during winter period in Kozan and during spring in Sivas. Spring sowings resulted in almost 100% earliness both of the cross combinations and the observed mean for flowering days. Biological yield in Kozan ranged from 0.77 to 7.66 g per plant, with a recorded mean of 3.61 g per plant. This trait ranged from 3.45 to 66.2 g per plant with a mean of 21.9 g per plant in Sivas (Table 2). Considerable variation in biological yield has been reported in prior studies (Ayub et al 2004; Bicer & Sakar 2008; Toklu et al 2009b). Biological yield is an important plant characteristic used in breeding programs for selection; therefore, these advanced lentil lines have the potential to increase biological yield utilized in breeding programs. Mean plant height was greater in Kozan when compared to Sivas for in cross combinations. This result showed that plant height is a trait highly affected by environmental conditions such as climate, soil type, altitude. Large diversity in phenotypic characters over locatios may be explained due to differences in environmental conditions (soil characteristics, agro-climatic features and rust diseases) and, spring and autumn sowings. Several researchers have reported greater diversity in plant height among lentil genotypes and exotic germplasm collections (Toklu et al 2009b; Mondal et al 2013). The mean number of branches per plant observed was 4.50 and 2.41 for advanced lentil lines (Table 2) and 2.80 and 1.98 for check varieties at Kozan and Sivas respectively. Bicer & Sakar (2008) reported that the number of branches per plant ranged from 1.4 to 2.8 among the different lentil genotypes, and Mondal et al (2013) reported significant variation in the number of branches per plant in lentil between mutant accessions and mother varieties. The number of pods per plant is directly connected to grain yield in lentil and varied from 12 to 74.3 with a mean of 37.5 at Kozan and 10.8 to 113.6 with a mean of 50.6 at Sivas for the advanced lentil lines. Greater diversity for this trait was observed among advanced lentil lines when compared to the check varieties (Table 2).

Several researchers also described high morphological diversity for the number of pods per plant (Toklu et al 2009b; Roy et al 2013; Mekonnen et al 2014). Due to great diversity in the yield components of these cross combinations could be evaluated for breeding and selection purposes. The weight of pods per plant exhibited a similar trend, as the number of pods per plant is due to the close relationship between two traits. A wide range of variability was detected for the weight of pods per plant in the advanced lentil lines at both locations. Most research shows that the weight of pods per plant is strongly correlated with grain yield (Sarwar et al 2010; 2013; Vanda et al 2013; Sharma et al 2014). Given this, the greater weight of pods per plant produced by these two cross combinations proves promising. The number of seeds also plays an important role in grain yield; therefore, this trait is crucial in improving high-yielding new varieties. The number of seeds per plant ranged from 1.33 to 34.6 with a mean of 9.45 and 3.60 to 87.4 with a mean of 36.5 at Kozan and Sivas, respectively. This is an indication of higher genotypic and phenotypic diversity for this trait; consequently, these advanced lines could be evaluated for number of seeds per plant to improve high-yielding new varieties and

Table 2- Mean, range and coefficient of variation (CV) for grain yield and yield components of the advanced lentil lines in two diverse locations

Çizelge 2- İleri kademedeki mercimek hatları ve kontrol çeşitlerinde dane verimi ve verim komponentlerine ilişkin iki farklı lokasyonda saptanan ortalama, değişim sınırları ve varyasyon katsayıları

Plant characteristic	*Location*	*Advanced lentil lines*			*Check varieties*	
		Mean±SD	*Range*	*CV (%)*	*Mean±SD*	*Range*
Days to 50% flowering	Kozan	107.6±1.00	106.0-110.0	0.97	*	*
	Sivas	57.6±2.71	54.0-66.0	7.71	63.0±4.55	57.0-67.0
Biological yield (g per plant)	Kozan	3.61±1.31	0.77-7.66	36.4	3.40±1.41	1.74-4.93
	Sivas	21.9±12.7	3.45-66.2	58.2	22.8±3.82	17.2-25.9
Plant height (cm)	Kozan	38.1±4.55	27.4-50.4	11.9	39.8±4.19	36.4-45.8
	Sivas	25.3±3.53	14.0-39.4	14.0	36.0±2.96	33.4-39.6
Number of branches per plant	Kozan	4.50±1.46	1.80-11.6	32.5	2.80±0.23	2.60-3.00
	Sivas	2.41±0.44	1.00-4.00	18.2	1.98±0.39	1.60-2.50
Number of pods per plant	Kozan	37.5±12.3	12.0-74.3	32.9	15.5±2.95	12.4-19.4
	Sivas	50.6±22.6	10.8-113.6	44.6	72.3±15.1	58.2-93.6
Weight of pods per plant (g)	Kozan	0.36±0.26	0.05-1.44	72.8	0.15±0.09	0.06-0.26
	Sivas	9.15±5.61	1.40-25.8	61.3	8.48±4.25	2.45-11.55
Number of seeds per plant	Kozan	9.45±6.73	1.33-34.6	71.2	3.73±1.39	2.00-5.20
	Sivas	36.5±20.6	3.60-87.4	56.4	41.0±16.7	16.8-53.5
1000-seed weight (g)	Kozan	31.2±8.24	12.0-51.7	26.4	19.3±10.4	10.0-34.2
	Sivas	31.4±6.60	12.5-44.0	21.0	27.7±2.80	23.6-29.8
Weight of seeds per plant (g)	Kozan	0.24±0.20	0.04-1.14	85.9	0.07±0.04	0.02-0.10
	Sivas	3.07±0.88	0.40-5.46	28.5	2.59±1.55	0.39-3.93

*, data could not obtained; SD, standard deviation; CV, coefficient of variation

in breeding programs. Similarly, Bicer & Sakar (2008), Toklu et al (2009b) and Mekonnen et al (2014) reported a high morphological diversity for the number of seeds per plant. The 1000-seed weight ranged from 12 to 51.7 g with a mean of 31.2 g at Kozan and 12.5 to 44 g with a mean of 31.4 g at Sivas. A higher phenotypic diversity was observed in the advanced lentil lines in comparison to the check varieties. Considerable 1000-seed weight variations were reported between newly developed lentil genotypes (Solanki et al 1999; Tyagi & Khan 2011). The weight of seeds per plant ranged from 0.04 to 1.14 g with a mean of 0.24 g at Kozan and 0.40 to 5.46 with a mean of 3.07 g at Sivas. A higher phenotypic diversity was observed for the advanced lentil lines when compared to the check varieties. Plant grain yield, along with grain quality, is one of the main objectives for plant breeders. Several researchers reported large variations in grain yield per plant for lentil genotypes (Solanki et al 1999; Sarwar et al 2010; Tyagi & Khan 2011; Vanda et al 2013; Mekonnen et al 2014; Sharma et al 2014).

These advanced lentil lines used in this study have the potential to increase yield in lentil.

A wide range of variability of seed K, Ca, Mg, Zn, Fe, Cu and Mn concentrations was found within the advanced lentil lines and check varieties (Table 3). Several researchers have reported that people need to consume at least 20 minerals and vitamins for balanced nutrition. Fe, Zn, Cu, Ca, Mg, I and Se are the most commonly lacking minerals in the human diet (White & Broadley 2009). In our research, the advanced red lentil lines investigated were found to have valuable phenotypic diversity for K, Ca, Mg, Zn, Fe, Cu, and Mn concentrations. Khan et al (1987) revealed valuable diversity for Ca, P, Fe, Zn, Mn, Cu, Ni and phytate contents among the improved lentil lines. Solanki et al (1999) reported considerable variation among the lentil genotypes for Ca, K, Fe and tannin contents, and Karaköy et al (2012) reported impressive variation in the micro- and macroelement concentrations in 39 lentil landraces. Breeding has proved to be the most affective method seed biofortification (White & Broadley 2005; 2009), with this in mind, crosses used in this study could provide plant breeders with a promising source of mineral rich seeds. Fe and Zn deficiencies are two of humanity's main nutritional problems. Biofortified crops are therefore gaining importance for human nutrition worldwide. In our research, Fe concentration ranged from 29.8 to 185.7 mg kg^{-1} with a mean of 56.1 mg kg^{-1} at Kozan and 19.9 to 142.5 mg kg^{-1} with a mean of 45.7 mg kg^{-1} at Sivas (Table 3). Great diversity in Fe concentration was observed in the advanced lentil lines when compared to the check varieties. Because

Table 3- Mean, range and coefficient of variation (CV) for seed mineral concentrations of lentil advanced lines and check varieties in two diverse locations

Çizelge 3- İleri kademedeki mercimek hatları ve kontrol çeşitlerinde dane mineral madde içeriğine ilişkin iki farklı lokasyonda saptanan ortalama, değişim sınırları ve varyasyon katsayısı

Plant characteristic	*Location*	*Advanced lentil lines*			*Check varieties*	
		Mean±SD	*Range*	*CV (%)*	*Mean±SD*	*Range*
K (mg 100 g^{-1})	Kozan	759.4±92.6	560.9-1121.1	12.2	947.9±37.9	903.9-991.4
	Sivas	907.2±91.2	667.7-1134.9	10.1	966.4±83.1	889.1-1061.5
Ca (mg 100 g^{-1})	Kozan	42.4±11.7	12.6-93.9	27.5	48.0±3.99	43.8-53.4
	Sivas	61.5±21.7	25.1-172.4	35.2	56.1±3.41	51.6-59.8
Mg (mg 100 g^{-1})	Kozan	125.9±17.7	100.6-213.1	14.0	165.6±2.45	163.5-169.2
	Sivas	146.8±9.67	122.2-196.7	6.59	141.9±11.7	130.5-155.8
Zn (mg kg^{-1})	Kozan	45.2±8.09	30.6-96.7	17.9	41.8±2.32	39.7-44.7
	Sivas	50.4±11.8	23.7-87.2	23.3	62.2±7.22	53.6-70.9
Fe (mg kg^{-1})	Kozan	56.1±15.3	29.8-185.7	27.4	41.3±1.90	38.7-42.8
	Sivas	45.7±13.8	19.9-142.5	30.2	49.2±4.45	42.8-53.1
Cu (mg kg^{-1})	Kozan	11.7±1.77	8.5-17.5	15.1	12.0±1.88	10.1-14.6
	Sivas	11.9±2.40	5.52-23.1	20.1	13.9±1.46	12.6-16.0
Mn (mg kg^{-1})	Kozan	19.1±3.05	12.8-27.2	16.0	17.2±1.58	15.0-18.7
	Sivas	16.5±3.41	8.24-36.2	20.6	15.9±0.94	14.5-16.7

SD, standard deviation; CV, coefficient of variation of the higher phenotypic diversity for seed Fe concentration, these crosses could be evaluated for biofortificaion of newly developed lentil varieties. Seed Zn concentration ranged from 30.6 to 96.7 mg kg^{-1} with a mean of 45.2 mg kg^{-1} at Kozan and 23.7 to 87.2 mg kg^{-1} with a mean of 50.4 mg kg^{-1} at Sivas. The valuable phenotypic diversity of both Fe and Zn concentraion in advanced lentil lines indicate the potential of these crosses to be used in seed mineral concentration studies.

The correlation coefficients between the yield components and mineral concentrations of advanced lentil lines are presented in Table 4. Days to 50% flowering was positively correlated with plant height, number of branches per plant, Fe and Mn concentrations but was negatively correlated with biological yield, number of pods per plant, weight of pods per plant, number of seeds per plant, weight of seeds per plant, and K, Ca, Mg, and Zn concentrations. Biological yield showed a positive and significant correlation with the number of pods per plant, weight of pods per plant, number of seeds per plant, 1000-seed weight, weight of seeds per plant, and K, Ca, Mg and Zn concentrations but were negatively correlated with plant height and number of branches per plant, Fe and Mn concentrations. Plant height showed a significant positive association with the number of branches per plant and Mn concentration and a significant negative association with the number of pods per plant, weight of pods per plant, number of seeds per plant, weight of seeds per plant, and K, Ca, Mg and Zn concentrations. The number of branches per plant showed a significant negative correlation with the weight of pods per plant, number of seeds per plant, weight of seeds per plant, and K, Ca and Mg concentrations in seeds. The number of pods per plant showed a positive significant correlation with the weight of pods per plant, number of seeds per plant, weight of seeds per plant, 1000-seed weight, Ca, Mg and Zn concentrations. The weight of pods per plant showed a positive significant correlation with the number of seeds per plant, 1000-seed weight, weight of seeds per plant, and K, Ca, Mg and Zn concentrations in seeds. The number of seeds per plant was positively correlated with the 1000-seed weight, weight of seeds per plant and K, Ca, Mg and Zn concentrations. 1000-seed weight was negatively correlated with seed K and Mg concentrations but was positively correlated with weight of seeds per plant. The weight of seeds per plant was positively correlated with K, Ca, Mg and Zn concentrations while negatively correlated with Fe and Mn concentrations. Seed K concentration was positively correlated with Ca, Mg, Zn and Cu concentration but was negatively correlated with Fe concentration. Seed Ca concentration showed a positive significant correlation with Mg and Zn concentrations but was negatively with Fe concentration. Seed Mg concentration was positively correlated with seed Zn and Cu concentration but were negatively correlated with seed Fe and Mn concentrations. Seed Zn concentration was positively correlated to seed Fe, Cu and Mn concetrations. Fe concentration showed positive significant association with Cu and Mn concentrations. Cu concentration was positively correlated to seed Mn concentration. Sarwar et al (2010) reported that seed yield showed a positive phenotypic correlation with the grain filling period, plant height, branches per plant, pods per plant and harvest idex, and improvement within this type of lentil population is possible by selecting plants with a relatively long grain filling period, increased number of pods and high harvest index. The results of our research showed a positive significant correlation between plant grain yield and biological yield, number of pods per plant, weight of pods per plant and number of seeds per plant. These findings are in accordance with the findings of Sarwar et al (2010), Kayan & Olgun (2012), Sarwar et al (2013), and Sharma et al (2014), who reported that the biological yield, number of pods, seeds per plant and harvest index are the yield components that most improve grain yield in lentil. The strong, significant negative correlation between plant grain yield and days to flowering indicate the importance of the grain filling period in lentil. Abo-Hegazy et al (2012) also revealed a negative correlation between plant grain yield and days to 50% flowering. In the last decade, mineral malnutrition is considered to be among the most serious global challenges relevance

Table 4- Correlation coefficients between the agromorphological characteristics and micronutrient concentrations of advanced lentil lines

Çizelge 4- İleri kademedeki mercimek hatlarında agromorfolojik karakterler ile dane mineral madde konsantrasyonları arasındaki korelasyon katsayıları

Plant trait	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
1- Days to flowering	1														
2- Biological yield	-0.72**	1													
3- Plant height	0.84**	-0.45**	1												
4- No. of branches per plant	0.69**	-0.41**	0.64**	1											
5- No. of pods per plant	-0.35**	0.68**	-0.10*	0.04	1										
6- Weight of pods per plant	-0.75**	0.83**	-0.49**	-0.46**	0.69**	1									
7- Number of seeds per plant	-0.60**	0.83**	-0.33**	-0.35**	069**	0.92**	1								
8- 1000-seed weight	-0.02	0.17**	0.08	-0.04	0.11*	0.19**	0.17**	1							
9- Weight of seeds per plant	-0.91**	0.82**	-0.70**	-0.61**	0.50**	0.89**	0.83**	0.09**	1						
10- K	-0.62**	0.38**	-0.50**	-0.49**	0.08	0.39**	0.27**	-0.18**	0.53**	1					
11- Ca	-0.47*	0.40**	-0.41**	-0.32**	0.40**	0.42**	0.37**	0.01	0.46**	0.14*	1				
12- Mg	-0.59**	0.41**	-0.52**	-0.41**	0.21**	0.42**	0.40**	-0.12*	0.59**	0.57**	0.42**	1			
13- Zn	-0.24**	0.22**	-0.25**	-0.14**	0.20**	0.14**	0.09*	0.02	0.19**	0.30**	0.29**	0.28**	1		
14- Fe	0.34**	-0.22**	0.33**	0.19**	-0.08	-0.29**	-0.24**	0.06	-0.33**	-0.12*	-0.11*	-0.21**	0.31**	1	
15- Cu	-0.06	0.06	-0.09	-0.06	-0.03	-0.06	-0.05	0.06	-0.02	0.28**	-0.04	0.14*	0.60**	0.45**	1
16- Mn	0.37**	-0.11*	0.39**	0.17**	-0.04	-0.19	-0.14**	0.08	-0.31**	-0.11	0.05	-0.12*	0.12*	0.53**	0.22**

*, significant at P<0.05; **, significant at P<0.01

to human nutrition and health (Grusak 2002; Welch & Graham 2004; White & Broadley 2005; 2009). Plant breeding efforts including the utilization of genetic resources and additional agricultural approaches reported among the most effective factors to overcome this problem (Graham et al 2007; Mayer et al 2008). In our study, we observed great variations among the lentil advanced lines for researched mineral elements. Our results are in accordance with above explanations and promising lentil lines could be used to improve new lentil varieties and spesific breeding purposes.

4. Conclusions

In conclusion, utilizing genetic resources in breeding and crop improvement is one of the most valuable ways to increase agricultural production in lentil and to improve food security for the world's population. In our study, we found considerable variations among the researched plant traits both agromorphological and nutrient-related traits in lentil advanced lines. This valuable variation could be used to develop new lentil varieties and different breeding purposes. Another issue is the importance of agromorphological and molecular characterization of lentil genetic resources for important plant characteristics. The two crosses used in this study were selected in accordance with the results of previous agromorphological and molecular caharacterization studies (Toklu et al 2009a, b), and parental genotypes were chosen. These results also showed that the improvement of biofortified lentil lines is possible using genetic resources.

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References

Abo-Hegazy S R E, Selim T & El-Emam E A A (2012). Correlation and path co-efficient analysis of yield and some yield components in lentil. *Egyptian Journal of Plant Breeding* **16**(3): 147-159

Alcock N W (1987). A hydrogen-peroxide digestion system for tissue trace-metal analysis. *Biological Trace Element Research* **13**: 363-370

Ayub K, Hashmi N I & Khan A (2004). Performance of exotic lentil varieties under rainfed conditions in Mingora (NWFP) Pakistan. *Online International Journal of Biological Sciences* **1**(5): 343-344

Bicer B T & Sakar D (2008). Studies on variability of lentil genotypes in Southeastern Anatolia of Turkey. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* **36**(1): 20-24

Blair M W (2013). Mineral biofortification strategies for food staples: The Example of Common Bean. *Journal of Agricultural and Food Chemistry* **61**: 8287-8294

Cubero J I (1981). Origin, taxonomy and domestication. In: Webb C & Hawtin G (Eds), *Lentils*, CAB, Slough, UK, pp. 15-38

Gepts P (2006). Plant genetic resources conservation and utilization: The accomplishments and future of a societal insurance policy. *Crop Science* **46**: 2278-2292

Graham R D, Welch R M, Saunders D A, Ortiz-Monasterio I, Bouis H E, Bonierbale M, de Haan S, Burgos G, Thiele G & Liria R (2007). Nutritious subsistence food systems. *Advances in Agronomy* **92**: 1-74

Grusak M A (2002). Enhancing mineral content in plant food products. *Journal of the American College of Nutrition* **21**: 178-183

Iqbal A, Khalil I A, Ateeq N & Khan M S (2006). Nutritional quality of important food legumes. *Food Chemistry* **97**: 331-335

Karaköy T, Erdem H, Baloch F S, Toklu F, Eker S, Kilian B & Özkan H (2012). Diversity of macro- and micronutrients in the seeds of lentil landraces. *The Scientific World Journal* **2012**: 1-9

Kayan N & Olgun M (2012). Evaluation of yield and some yield components in lentil (*Lens culinaris* Medik). *International Journal of Agriculture: Research and Review* **2**: 834-843

Khan M A (1987). Nutritional attributes of food legumes. *Progressive Farming (Pakistan)* **7**: 36-40

Khan M A, Rana I A, Ullah I & Jaffery S (1987). Physiochemical characters and nutrient composition of some improved lines of lentils grown in Pakistan. *Journal of Food Composition and Analysis* **1**: 65-70

Lev-Yadun S, Gopher A & Abbo S (2000). The cradle of agriculture. *Science* **288**: 1602-1603

Mayer J E, Pfeiffer W H & Beyer P (2008). Biofortified crops to alleviate micronutrient malnutrition. *Current Opinion in Plant Biology* **11**: 166-170

Mekonnen F, Mekbib F, Kumar S, Ahmed S & Sharma T R (2014). Agromorphological traits variability of the Ethiopian lentil and exotic genotypes. *Advances in Agriculture* **2014**: Article ID 870864

Mondal M M A, Puteh A B, Abdul Malek M, Roy S & Rafii Yusop M (2013). Contribution of morpho-physiological traits on yield of lentil (*Lens culinaris* Medik). *Australian Journal of Crop Science* **7**: 1167-1172

Muehlbauer F J, Cho S, Sarker A, McPhee K E, Coyne C J, Rajesh P N & Ford R (2006). Application of biotechnology in breeding lentil for resistance to biotic and abiotic stress. *Euphytica* **147**: 149-165

Roy S, Islam M A, Sarker A, Malek M A & Ismail M R (2013). Determination of genetic diversity in lentil germplasm based on quantitative traits. *Australians Journal of Crop Science* **7**(1): 14-21

Sarwar G, Abbas G & Asghar M J (2010). Genetic study for quantitative traits in F_5 generation of lentil (*Lens culinaris* Medik). *Journal of Agricultural Research* **48**(3): 279-288

Sarwar G, Abbas G & Asghar M J (2013). Quantitatıve analysis of yield related traits in lentil (*Lens culinaris* Medik) germplasm. *Journal of Agricultural Research* **51**(3): 239-246

SAS (2007). SAS Institute. JMP 7.0 Users guide. Carry, NC: Release SAS Institute Inc

Shahzad Z, Rouached H & Rakha A (2014). Combating mineral malnutrition through iron and zinc biofortification of cereals. *Comprehensive Reviews in Food Science and Food Safety* **13**(3): 329-346

Sharma V, Paswan S K, Sıngh V K & Khandagale S (2014). Correlation and path coefficient analysis of economically ımportant traits in lentil (*Lens culinaris* Medik) germplasm. *The Bioscan* **9**(2): 819-822

Singh M, Bisht I S, Kumar S, Dutta M, Bansal K C, Karale M, Sarker A, Amri A, Kumar S & Datta S K (2014). Global wild annual Lens collection: A potential resource for lentil genetic base broadening and yield enhancement. *PLoS One* **9**: e107781. doi:10.1371/journal.pone.0107781

Solanki I S, Kapoor A C & Singh U (1999). Nutritional parameters and yield evaluation of newly developed genotypes of lentil *(Lens culinaris* Medik). *Plant Foods for Human Nutrition* **54**: 79-87

Toklu F, Karaköy T, Hakli E, Bicer T, Brandolini A, Kilian B & Özkan H (2009a). Genetic variation among lentil (*Lens culinaris* Medik) landraces from Southeast Turkey. *Plant Breeding* **128**(2): 178-186

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

Tyagi S D & Khan M H (2011). Correlation, path-coefficient and genetic diversity in lentil (*Lens culinaris* Medik) under rainfed conditions. *International Research Journal of Plant Science* **2**(7): 191-200

Upadhyaya H D, Thudi M, Dronavalli N, Gujaria N, Singh S, Sharma S & Varshney R K (2011). Genomic tools and germplasm diversity for chickpea improvement. *Plant Genetic Resources* **9**(1): 45-58

Vanda M, Khodambashi M, Houshmand S, Shiran B & Amiri-Fahlian R (2013). Determination of gene action and heritability for some biometrical traits in lentil (*Lens culinaris* Medik) using $F_{2:3}$ families. *International Journal of Agriculture and Crop Sciences* **5**(13): 1427-1431

Welch R M & Graham R D (2004). Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany* **55**: 353-364

White P J & Broadley M R (2005). Biofortifing crops with essential mineral elements. *Trends in Plant Science* **10**(12): 586-593

White P J & Broadley M R (2009). Biofortification of crops with seven mineral elements often lacking in human diets-iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytologist* **182**: 49-84

WHO (1999). Malnutrition worldwide. Geneva, Switzerland: World Health Organization. http://www.who.int/nut/malnutrition_worldwide.htm. 1-13