

Assessment of Mineral Content Variations for Biofortification of the Bean Seed

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Abstract. Germplasm collections are very important for breeder to develop new cultivars with high mineral nutrients and yield. Eighty-three *Phaseolus* landraces were collected from different provinces of Western Anatolia Region of Turkey in 2015-2016. Twenty common bean lines were selected according to morphological characterization results and weighted scaling method in 2016. Phosphorus (P), potassium (K), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), calcium (Ca), and magnesium (Mg) contents of these twenty common bean lines and two commercial cultivars were tested under field conditions. Randomized block design with three replicates was used for analysis in 2017 growing season on the experimental farm of Bolu Abant İzzet Baysal University. The results showed high level of variation among lines and cultivars in terms of P (0.94-1.30%), K (2.38-3.59%), Cu (7.80-14.80 mg kg⁻¹), Zn (19.74-66.68 mg kg⁻¹), Mn (7.46-27.25 mg kg⁻¹), Fe (48.98-182.45 mg kg⁻¹), Ca (0.18-0.48 mg kg⁻¹) and Mg (0.56-0.71 mg kg⁻¹) contents. Positive correlations were found between K and Zn ($r=0.447$; $P<0.05$), P and Fe ($r=0.485$; $P<0.05$), Ca and Mg ($r=0.693$; $P<0.01$). In principal component analysis (PCA), the first 4 principal components accounted for approximately 73% of the total variability. The lines, Ylv-14, Ylv-32, Blck-7, Blksr-3 and Brs-22 had superior mineral contents for Fe and P, Cu and Mn, Ca and Mg, Zn, and K, respectively. Therefore, these lines represent promising candidates for biofortifying the bean seed and can be registered as cultivars in Turkey. Moreover, these lines will be used further for identifying the QTL regions by developing biparental mapping populations for an effective breeding program in Turkey in near future.

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Fasulye Tohumunun Biyofortifikasyonu için Mineral İçerik Varyasyonlarının Değerlendirilmesi

Anahtar kelimeler:

Biyofortifikasyon, mikro- makro mineral, *Phaseolus vulgaris* L.

Özet. Genetik kaynaklar ıslahçıların yüksek verim ve mineral içeriğine sahip yeni çeşitler geliştirebilmesi için çok önemlidir. 2015-2016 yılları arasında Türkiye'nin Batı Anadolu bölgesinin farklı bölgelerinden seksen üç *Phaseolus* popülasyonu toplanmıştır. Morfolojik karakterizasyon sonuçları ve tartılı derecelendirmeye göre yirmi fasulye hattı 2016 yılında seçilmiştir. Yirmi fasulye hattının ve iki ticari çeşidin fosfor, potasyum, bakır, çinko, mangan, demir, kalsiyum ve magnezyum içerikleri tarla koşullarında test edilmiştir. Deneme 2017 yılı yetiştirme periyodunda Bolu Abant İzzet Baysal Üniversitesi, Araştırma ve Uygulama Alanı'nda tesadüf blokları deneme desenine göre üç tekrarlamalı olarak yürütülmüştür. Sonuçlar, fasulye hat ve çeşitleri arasında P (%0.94-1.30), K (%2.38-3.59), Cu (7.80-14.80 mg kg⁻¹), Zn (19.74-66.68 mg kg⁻¹), Mn (7.46-27.25 mg kg⁻¹), Fe (48.98-182.45 mg kg⁻¹), Ca (0.18-0.48 mg kg⁻¹) ve Mg (0.56-0.71 mg kg⁻¹) yüksek oranda varyasyon göstermiştir. K ve Zn ($r=0.447$; $P<0.05$), P ve Fe ($r=0.485$; $P<0.05$), Ca ve Mg ($r=0.693$; $P<0.01$) arasında pozitif yönde korelasyon bulunmuştur. Ana bileşen analizine göre toplam çeşitliliğin %73'ünden ilk 4 temel komponentin sorumlu olduğu görülmüştür. Ylv-14, Ylv-32, Blck-7, Blksr-3 ve Brs-22 hatları sırasıyla Fe ve P, Cu ve Mn, Ca ve Mg, Zn, ve K bakımından daha yüksek mineral içeriğine sahip olduğu tespit edilmiştir. Bu sebeplerden dolayı, bu hatlar fasulye tohumlarının biyofortifikasyonu için ümitvar adayları temsil etmekte ve Türkiye'de çeşit olarak tescillenebilir. Ayrıca bu hatlar, yakın gelecekte etkili ıslah programları için biparental haritalama popülasyonu geliştirilerek QTL bölgelerinin tanımlanması amacıyla da kullanılabilir.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is one of the oldest domesticated crops of the New World (Broughton *et al.*, 2003). It is a self-pollinated crop ($2n = 2x = 22$) with a small genome size of 587 Mbs (Schmutz *et al.*, 2014). *Phaseolus vulgaris* L., originated in Latin America, and have two diverse gene pools, Mesoamerican gene pool with small seeds and Andean gene pool with large seeds (Bitocchi *et al.*, 2017). The Mesoamerican gene pool is predominantly found from Colombia up to Mexico, while Andean gene pool extends between South Peru to North Western Argentina (Kwak and Gepts 2009).

Phaseolus vulgaris L. is the most widely cultivated grain legume, and greatly preferred in many parts of Africa, Latin America and Southern Europe (Broughton *et al.*, 2003). Common bean is a vital source of nutrients for nearly 300 million people worldwide (Petry *et al.*, 2015), and known as "poor man's meat" because of its high mineral, protein, and vitamin content (Sperotto and Ricachenevsky 2017), providing health benefits associated with regular consumption (Bitocchi *et al.*, 2017).

Micronutrient malnutrition is a main public health problem in many parts of the world, which is known as "hidden hunger" (Welch and Graham 2004). Micronutrient deficiencies have raised in the last decades in developed and developing countries (Graham *et al.*, 2001). Particularly, the deficiency of Fe and Zn is a crucial public health problem, and negatively affects the health, lifespan and productivity over 4 billion people worldwide (WHO 2009; Khan *et al.*, 2008).

The production of micronutrient enhanced varieties (biofortified) using agricultural and genetical methods can provide a cost-effective way to overcome micronutrient deficiencies by improving the bioavailability of these important nutrients (Duc *et al.*, 2010). "Biofortification" or "biological fortification" is the process of improving the nutritional status in staple crops by means of modern biotechnology techniques, traditional plant breeding, and agronomic practices (Garg *et al.*, 2018). Collection of local germplasm and characterization of natural biodiversity as a source of novel alleles for biofortifying the crops are of prime importance in 21st century breeding programs. For breeders, the first step of the biofortification in food crops is to understand the current genetic diversity in germplasm collections (Baloch *et al.*, 2014). All mineral elements that are most frequently lacking in human diets are present in genetic variations, and this can be used in breeding

studies to increase the levels of minerals and vitamins in crops (White and Broadley 2005). Numerous studies have been conducted to determine the nutritional status of grain legumes. Earlier work by Pinheiro *et al.* (2010) found a high degree of variability in P, Fe, Zn, Cu, Mn, Ca and protein content in a collection of 155 accessions of ancient Portuguese common bean (*Phaseolus vulgaris* L.) seeds. In another study, Dutta *et al.* (2016) found a considerable genetic variation in the seed macro and micro-nutrients content with high antioxidant activity among the common bean landraces of Lushai hills of India.

Common bean lines with high levels of nutrients can be combined with superior agronomic characteristics and high yields for better selection, and can be used for biofortification strategies. Studies in Turkish grain legume germplasms (Çiftçi 2009; Kantar 2010; Madakbaş and Ergin 2011; Çiftçi 2012; Elkoca and Çınar 2015; Yeken 2018a; Nadeem *et al.*, 2018) focused mostly on phenological and morphological properties, resistance to important diseases, and quality characteristics. Assessment of mineral content and yield is also important in terms of providing high level of nutrition and high yield at the same time while breeding for new varieties. However, mineral contents of the common bean seeds have not been evaluated before in Western Anatolia Region of Turkey for a better selection of common bean varieties while breeding for fortification and higher yield. Therefore, our objective was to analyse the seed mineral content (P, K, Cu, Zn, Mn, Fe, Ca, and Mg) of twenty common bean lines selected for their high yield properties from a germplasm of Western Anatolia Region of Turkey and two commercial cultivars tested under field conditions.

MATERIAL AND METHOD

Plant Material and Crop Sowing

Eighty-three *Phaseolus* landraces were collected from different provinces (Düzce, Yalova, Bilecik, Bursa, Balıkesir, Çanakkale) of Western Anatolia Region of Turkey in 2015-2016. Twenty common bean lines (*Phaseolus vulgaris* L.) were selected through single plant selection from these local landraces according to morphological characterization results and weighted scaling method in 2016. These promising lines and two commercial cultivars were used as genetic materials in this study. All the passport data of common bean lines were given Table 1 (Figure 1). These common bean lines were tested in randomized block design with three replicates together with two commercial

cultivars in 2017 at the research and implementation area of Bolu Abant İzzet Baysal University (BAIBU) (40°44'46.71"N, 31°37'45.18"E), Turkey. All genotypes were sown on May 2017 in the plots consisting two rows of 4 m long with a row spacing of 45 cm for bush types, 70 cm for climber types, and intra row spacing of 10 cm. Common beans were harvested in September 2017. Total precipitation was around 36.9 kg m⁻² during the growing season (from sowing to physiological maturity). The experimental area had a loamy structure revealing a slightly alkaline character. While the soil of the experimental area was poor in terms of organic matter (1.80-1.86%), it was rich in terms of available K (264.3-273.3 mg kg⁻¹) and P (20.4-31.5 mg kg⁻¹). All mineral elements were within sufficient or excessive limit values except for Zn content being deficient (Table 2) (Sönmez *et al.*, 2018). After soil analysis, a fertilizer rate of 4 kg of nitrogen and was given at the time of sowing in the form of ammonium sulphate (21%). Standard local agricultural practices were applied equally to eliminate the role of environment in all the plots.

Micro- and Macronutrient Analysis

Micro- and macronutrient concentrations such as P, K, Ca, Mg, Fe, Zn, Cu and Mn were investigated in seeds obtained from common bean lines and commercial cultivars. Seed samples were taken from

every landrace with 3 replications and seeds were bulked. A closed microwave digestion system (ETHOS EASY, Milestone, Italy) was used to digest the samples (0.2 g) using 5 mL of concentrated nitric acid (65%) and 2 ml of hydrogen peroxide (35%) (Bremner 1965; Gesto-Seco *et al.*, 2009). After digestion, solutions were transferred to flasks and made up to a final volume of 20.0 mL with ultra-pure water and then analyzed for mineral nutrients (K, Ca, Mg, Fe, Zn, Cu and Mn) with Atomic Absorption Spectrophotometer (Shimadzu AA-7000), and P was measured colorimetrically at 430 nm in the spectrophotometer (Murphy and Riley 1962; Kacar and İnal 2008; Karaköy and Demirbaş 2017). Mineral contents of each sample were analyzed in triplicates.

Statistical Analysis

Statistical evaluation of data was performed using analysis of variance (ANOVA), and significant differences between accessions were detected with an α of 0.05. Correlations between minerals were calculated using the Pearson correlation. Principal component analysis (PCA) based on mineral elements was used to identify the patterns of variance after varimax rotation within the set of twenty common bean lines and two commercial cultivars. XLSTAT 2016 (Addinsoft, New York, USA) was used to perform statistical analyses.

Table 1. Passport data of common bean lines.

Çizelge 1. Fasulye hatlarının pasaport bilgileri.

No.	Landraces	Geographical province	Latitude (N)	Longitude (E)
1	Ylv-14	Yalova-Çiftlikköy-Kabaklı	40°39'55.92"	29°24'43.66"
2	Ylv-28	Yalova-Merkez-Kurtköy	40°33'12.70"	29°12'52.17"
3	Ylv-31	Yalova-Merkez-Hacimehmet	40°36'56.22"	29°14'37.62"
4	Ylv-32	Yalova-Merkez-Sugören	40°33'38.32"	29°19'34.07"
5	Blksr-3	Balıkesir-Manyas-Salur	40° 5'58.61"	27°56'16. 5"
6	Blksr-4	Balıkesir-Manyas-Akçaova	40° 7'16. 8"	27°51'15.26"
7	Blksr-19	Balıkesir-Sındırgı-Kürendere	39°19' 6. 02"	28°34' 8.21"
8	Brs-3	Bursa-Yenişehir-Osmaniye	40°10'18.45"	29°37'15.12"
9	Brs-4	Bursa-Inegöl-Cerrah	40° 4'18.83"	29°26'7.75"
10	Brs-21	Bursa-Kestel-Kızılören	40° 7' 39.19"	29°21'9.43"
11	Brs-22	Bursa-Kestel-Aksu	40°10'2.02"	29°18'58.01"
12	Brs-23	Bursa-Kestel-Aksu	40°10'2.02"	29°18'58.01"
13	Brs-24	Bursa-Orhaneli-Küçükorhan	39° 48 '9.04"	39°48'9.04"
14	Dzc-2	Düzce-Merkez-Derdin	40°42'30.06"	31°13'20.51"
15	Dzc-3	Düzce-Merkez-Derdin	40°42'30.06"	31°13'20.51"
16	Blck-7	Bilecik-Pazaryeri-Dereköy	39°59'12.52"	29°51'7.17"
17	Çnk-2	Çanakkale-Yenice-Çınarcık	39°57'6.22"	27°10'54.75"
18	Çnk-4	Çanakkale-Biga-Aşağıdemirci	40°14'38.70"	27°22'17.65"
19	Çnk-6	Çanakkale-Biga-Gerlengeç	40°17'26.36"	27°25'14.56"
20	Çnk-8	Çanakkale-Bayramiç-Beşik	39°44'15.48"	26°41'34.82"
21	Göynük-98	Cultivar/ Transitional Zone Agricultural Research Institute, Eskisehir / Turkey		
22	Önceler-98	Cultivar/ Transitional Zone Agricultural Research Institute, Eskisehir / Turkey		

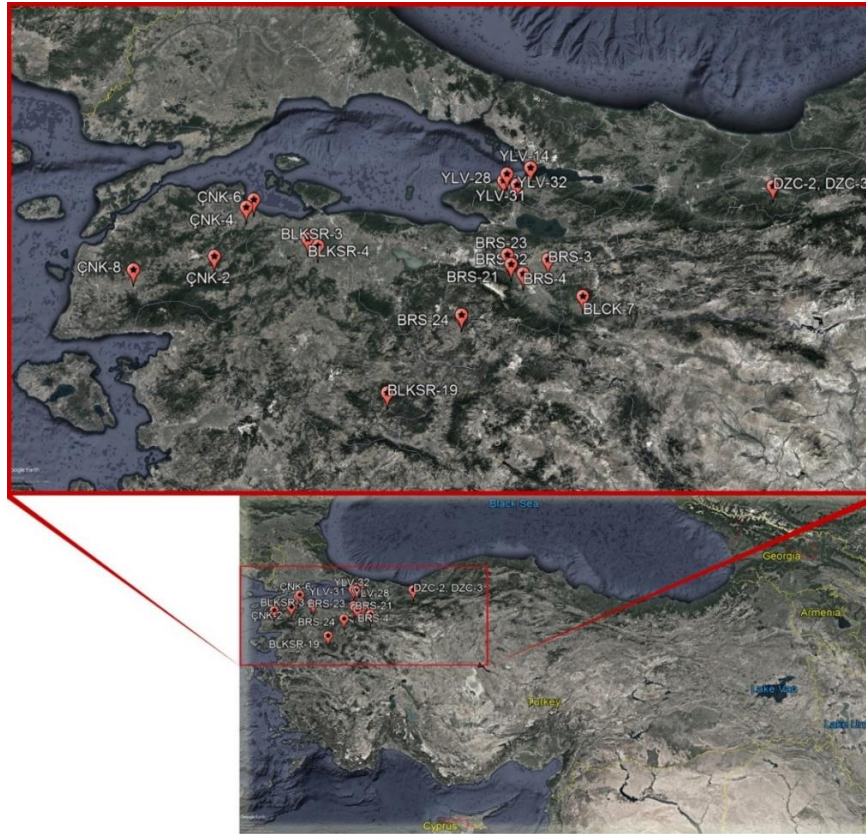


Figure 1. Map of North West of Turkey from which common bean landraces were collected. Provinces where landraces were collected were marked in red.

Şekil 1. Türkiye'nin kuzey batısından toplanılan fasulye populasyonlarının haritası. Fasulye populasyonlarının toplandığı bölgeler kırmızı ile işaretlenmiştir.

Table 2. Physical characteristics and chemical data (0-20 cm and 20-40 depth layer) in experimental area of BAIBU where the *P. vulgaris* lines and cultivars were grown (Sönmez et al., 2018).

Çizelge 2. *P. vulgaris* hatlarının ve çeşitlerinin yetiştirildiği BAIBU araştırma alanı toprağının 0-20 ve 20-40 cm derinlik tabakasındaki fiziksel ve kimyasal özellikleri (Sönmez et al., 2018).

Parameters	Unit	0-20 cm	20-40 cm
EC	dS m ⁻¹	1.516	0.635
pH		7.59	7.84
Organic Matter	%	1.86	1.80
Phosphorus (P)	mg kg ⁻¹	31.5	20.4
Potassium(K)	mg kg ⁻¹	273.3	264.3
Calcium(Ca)	mg kg ⁻¹	4415	4446
Magnesium (Mg)	mg kg ⁻¹	210.2	213.9
Sodium (Na)	mg kg ⁻¹	64.30	67.42
Iron (Fe),	mg kg ⁻¹	16.62	17.46
Manganese (Mn)	mg kg ⁻¹	4.66	4.82
Zinc (Zn)	mg kg ⁻¹	2.42	2.10
Copper (Cu)	mg kg ⁻¹	42.90	46.08
Texture		Loamy	Loamy
Lime	%	0.63	0.74
Sand	%	50	50
Clay	%	22	22
Silt	%	28	28

RESULTS AND DISCUSSION

Landraces are very important for genetic and breeding studies. It is of great importance to investigate natural biodiversity as a new allelic source to improve yield, adaptability, better cooking characteristics and nutritional value of products in 21st century crop breeding programs. Turkey is not the origin and domestication center of common bean, but common bean landraces distributed in diverse area of Turkey harbor adequate amount of diversity. Characterization of common bean landraces in terms of their nutritional value is crucial for their effective utilization in breeding programs to improve the mineral status of common bean cultivars.

A comprehensive analysis of micronutrient (Zn, Fe, Cu, and Mn) and macronutrient (K, P, Ca, and Mg) concentrations was performed for common bean lines and cultivars. Correlations among eight mineral elements (P, K, Cu, Zn, Mn, Fe, Ca, and Mg) in twenty common bean lines and commercial cultivars are given in Table 3. Positive and significant correlations were found between P and Fe ($r=0.485$; $P<0.05$), K and Zn ($r=0.447$; $P<0.05$), Ca and Mg ($r=0.693$; $P<0.01$). On the other hand, Cu and Mn were not correlated with

any of the other minerals. Determination of correlations between minerals of a seed is critical for breeding programs in terms of selection of varieties. Selection of a desired mineral could improve the level of another mineral if there is a positive correlation between the two (Baloch et al., 2014). The positive associations found in this study indicates that selection of a bean with high mineral content may increase the amount of positively correlated mineral indirectly.

In previous studies, correlations were reported in numerous crops, such as *Phaseolus vulgaris* (Bebée et al., 2000; Pinheiro et al., 2010; Yeken et al., 2018b), lentil (Karaköy et al., 2012), and faba bean (*Vicia faba* L.) landraces from Turkey (Baloch et al., 2014). The P content was positively correlated with Fe in this study, and similar findings reported by Bebee et al. (2000) and Pinheiro et al. (2010) in common bean, Baloch et al. (2014) in faba bean and Karaköy et al. (2012) in lentil. Similarly, significant associations of K and Zn have been previously reported by Baloch et al. (2014) and Karaköy et al. (2012). In addition, seed Ca and Mg concentrations were significantly correlated to each other, and these results are in agreement with earlier

worked by Karaköy et al. (2012). Genetic linkage, pleiotropic, or environmental effects can affect correlations between traits, and the evolution of properties can be influenced by environmental factors in the same or opposite directions (Yücel et al., 2009; Karaköy et al., 2012).

The patterns of variation were evaluated by PCA using twenty common bean lines and commercial cultivars and based on 8 mineral traits. PCA analysis based on the correlation matrix revealed that first five components for all 8 mineral traits explained 87.48% of the total variance (Table 4). 21.28 % of the variation was explained by the first principal component (PC1). Mg and Ca had the highest contribution in PC1. The second principal component (PC2) was highly dependent on Zn and K, and accounted for 17.57% of the variability. The third principal component (PC3) accounted for 20.03% of total variability, and P and Fe content had the highest contribution in PC3. The fourth principal component (PC4) explained 13.75 % of the variability with high contribution of Cu and Fe. The first four principal components were important accounting for approximately 73% of the total variability.

Table 3. Correlation coefficients among the concentrations of seed mineral elements of common bean lines and commercial cultivars.

Çizelge 3. Fasulye hatlarının ve ticari çeşitlerin tohum mineral elementlerinin konsantrasyonları arasındaki kolerasyon katsayıları.

Variables	P	K	Cu	Zn	Mn	Fe	Ca	Mg
P (%)	1	-0.236	-0.021	0.089	-0.204	0.485*	-0.068	-0.407
K (%)		1	0.137	0.447*	-0.274	-0.154	-0.148	0.187
Cu (mg kg ⁻¹)			1	0.073	-0.031	0.149	-0.133	0.046
Zn (mg kg ⁻¹)				1	0.087	-0.177	-0.042	0.112
Mn (mg kg ⁻¹)					1	-0.126	0.231	0.276
Fe (mg kg ⁻¹)						1	-0.126	-0.206
Ca (mg kg ⁻¹)							1	0.693**
Mg (mg kg ⁻¹)								1

*P<0.05, **P<0.01.

Table 4. Cumulative percentages of variance explained by the first 5 principal components (PCs) of 20 common bean lines and 2 commercial cultivars for contents of some mineral elements.

Çizelge 4. Kümülatif varyans yüzdesi 20 fasulye hattı ve 2 ticari çeşidin bazı mineral elementlerin içerikleri için ilk 5 ana bileşen (PCs) ile açıklanmıştır.

	PC1	PC2	PC3	PC4	PC5
Ca (mg kg ⁻¹)	0.922	-0.079	0.054	-0.166	0.129
Mg (mg kg ⁻¹)	0.889	0.121	-0.286	0.125	0.066
Zn (mg kg ⁻¹)	0.008	0.958	0.056	0.002	0.099
K (%)	0.047	0.635	-0.312	0.198	-0.542
P (%)	-0.159	0.095	0.907	-0.125	-0.040
Fe (mg kg ⁻¹)	-0.038	-0.218	0.757	0.317	-0.112
Cu (mg kg ⁻¹)	-0.040	0.054	0.016	0.949	0.007
Mn (mg kg ⁻¹)	0.175	0.069	-0.141	0.037	0.921
Variability (%)	21.279	17.574	20.028	13.749	14.853
Cumulative %	21.279	38.853	58.881	72.630	87.483

Table 5 shows the concentrations of P, K, Cu, Zn, Mn, Fe, Ca, and Mg in the seeds of twenty common bean lines and two commercial cultivars including maximum, minimum, mean, coefficient of variation (CV) % and least significant difference (LSD) values. Statistical analysis of data revealed that bean lines selected from traditional landraces and cultivars were significantly different from each other ($p < 0.05$) for all the studied mineral traits. Moreover, majority of these lines showed significantly higher concentrations of seed mineral content for Fe, Mg, P, and Ca relative to the commercial cultivars. The P content varied from 0.94 (Çnk-4; Brs-23) to 1.30% (Ylv-32) with a mean value of 1.14%. The P content of commercial cultivars was lower than thirteen lines (Ylv-14,28,31,32; Brs-3,4,21; Çnk-6,8; Dzc-2,3; Blksr-3,19). The amount of K in the studied lines and cultivars varied between 2.38% for Ylv-28 and 3.59% for Brs-22 with an average of 2.75%. The K contents of five lines (Brs-21,22,23; Blksr-3; Çnk-2) were significantly higher than cultivars. The overall value of Cu contents between lines and cultivars was 11.77 mg kg⁻¹, ranging from 7.80 mg kg⁻¹ (Ylv-28) to 14.80 mg kg⁻¹ (Ylv-14). Compared to the cultivars, only Ylv-14 was found to have higher Cu content than cultivars. The average Zn content in lines and cultivars was 25.84 mg kg⁻¹ with the lowest Zn content being in Çnk-4 and Ylv-28 (19.74 mg kg⁻¹), and the highest value Blksr-3 (66.68 mg kg⁻¹) followed by Dzc-3, Brs-22,24. Mn levels varied between 7.46 and 27.25 mg kg⁻¹ with a mean level of 19.48 mg kg⁻¹. Only, two lines (Ylv-14 and Çnk-6) were higher in Mn content than cultivars. The mean Fe concentration of lines and cultivars was 100.92 mg kg⁻¹ and it varied between 48.98 mg kg⁻¹ (Göynük-98) and 182.45 mg kg⁻¹ (Ylv-32). Fe contents of fifteen lines (Ylv-14,28,31,32; Çnk-2,8; Blksr-19; Brs-3,4,21,22,24; Blck-7 and Dzc-2,3) were greater than cultivars. The highest value of Ca content was 0.478 mg kg⁻¹ (Blck-7) while the lowest value was 0.181 (Göynük-98), with an average value of 0.242 mg kg⁻¹. Blck-7, Çnk-6,8, Brs-3, 4, 22, 23, 24, Dzc-2, Blksr-19 and Ylv-28, 31 had significantly higher Ca concentrations than cultivars. Mg concentrations varied from 0.558 (Blksr-4) to 0.712 mg kg⁻¹ (Blck-7), and the mean value was 0.605 mg kg⁻¹. The Mg content of cultivars were higher than Blksr-4,19, Çnk-8, Dzc-3 and Ylv-32.

Pinheiro *et al.* (2010) reported that determination of the mineral content of common beans is important for breeding programs since obtaining elevated levels of minerals has a high value in terms of increasing nutritional quality of the beans. Different ranges for the minerals were reported in the literature (Beebe *et al.*, 2000; Moraghan and Grafton 2001; Pinheiro *et al.*,

2010; Dutta *et al.*, 2016; Yeken *et al.*, 2018b). The range of P concentration of common bean lines and cultivars (0.94-1.30%) were higher than previous studies conducted by Pinheiro *et al.* (2010), Dutta *et al.* (2016), and Yeken *et al.* (2018b). On the other hand, K levels of all lines and cultivars were higher than the levels reported by Pinheiro *et al.* (2010), but lower than Yeken *et al.* (2018b). The amount of Zn, Fe, Mn and Cu in the study were found partially similar to the previous studies (Beebe *et al.*, 2000; Pinheiro *et al.*, 2010; Dutta *et al.*, 2016; Yeken *et al.*, 2018b). For example, one of the possible explanations for high Fe content of seeds is the high Fe content of the soil (16.62 mg kg⁻¹ in 0-20 cm and 17.46 mg kg⁻¹ in 20-40 cm) of the experimental area shown by Sönmez *et al.*, 2018 (Table 2). Additionally, common bean seeds were identified as Mesoamerican germplasm (<25 g) and Andean counterpart (>25 g) using 100 seed weight (Gepts *et al.*, 1986). Seeds used in this study were described as Andean gene pool (data not shown). Compared to Mesoamerican gene pool, Andean and intergene- pool hybrids have higher Fe contents (Blair 2013). The Ca levels were detected lower than Yeken *et al.* 2018, however they showed partially similar results with Pinheiro *et al.* (2010). In addition, Mg content was found higher than Pinheiro *et al.* (2010) and similar to Yeken *et al.* (2018b). Most of lines had higher level of minerals than the cultivars. Moreover, different mineral levels in the seeds could be explained by genotype, soil composition, and growing season differences (Ceyhan *et al.*, 2008).

CONCLUSIONS

Mineral content of grain legumes is very important for developing and under-developed countries in terms of providing more nutrition for people, since grain legumes might be a cheaper and more available source of food. The range of Fe, Mg, P and Ca levels in common bean lines was greater than cultivars. In particular, some common bean lines tested in this study (Ylv-14 for Fe and P, Ylv-32 for Cu and Mn, Blck-7 Ca and Mg, Blksr-3 for Zn, and Brs-22 for K) can play a vital role for human consumption. These common bean lines and information of their mineral content in comparison with cultivars can be used as parents in common bean breeding programs to improve mineral quality of new cultivars. Moreover, these lines can be evaluated for identifying the QTL regions by developing biparental mapping populations for effective breeding program not only in Turkey but also other parts of the world in future studies.

Table 5. Seed mineral contents of common bean lines in comparison with commercial cultivars and LSD groups.

Çizelge 5. Fasulye hatlarının tohum mineral içeriklerinin ticari çeşitlerle karşılaştırılması ve LSD grupları.

	P (%)		K (%)		Cu (mg kg ⁻¹)		Zn (mg kg ⁻¹)		Mn (mg kg ⁻¹)		Fe (mg kg ⁻¹)		Ca (mg kg ⁻¹)		Mg (mg kg ⁻¹)	
Blck-7	1.12	h	2.42	o	12.42	e	22.93	g	23.85	cd	100.13	g	0.478	a	0.712	a
Blksr-3	1.19	ef	3.28	b	11.67	f	66.68	a	22.89	de	80.36	jk	0.226	ı	0.620	d
Blksr-4	1.07	ij	2.44	no	12.27	e	23.87	f	21.20	gh	76.86	l	0.210	l	0.558	n
Blksr-19	1.19	ef	2.77	g	11.28	gh	21.66	ij	19.24	ı	167.86	b	0.240	g	0.562	m n
Brs-3	1.18	fg	2.46	mn	10.79	ij	24.84	e	21.66	fg	85.10	ı	0.257	d	0.588	hı
Brs-4	1.21	cd	2.61	kl	10.53	jk	22.79	gh	22.66	ef	97.87	g	0.254	de	0.598	g
Brs-21	1.17	g	3.04	c	11.54	fg	21.12	j	7.53	j	119.15	c	0.190	o	0.587	hı
Brs-22	1.12	h	3.59	a	13.26	d	27.74	b	7.51	j	100.00	g	0.252	ef	0.629	c
Brs-23	0.94	l	3.05	c	12.51	e	25.96	d	21.84	efg	54.21	m	0.277	c	0.670	b
Brs-24	1.06	j	2.60	l	10.22	k	27.62	bc	24.31	bc	105.98	f	0.278	c	0.613	f
Çnk-2	1.00	k	2.99	d	11.06	hı	22.16	ghı	21.09	gh	110.90	e	0.218	j	0.630	c
Çnk-4	0.94	l	2.63	jk	11.10	hı	20.24	k	20.42	h	78.67	kl	0.215	k	0.613	ef
Çnk-6	1.21	cd	2.69	h	11.54	fg	22.74	gh	25.08	b	78.06	kl	0.281	b	0.592	h
Çnk-8	1.25	b	2.67	hı	11.23	gh	23.79	f	8.19	j	115.11	d	0.241	g	0.571	kl
Dzc-2	1.20	de	2.83	ef	13.46	cd	26.83	c	22.58	ef	82.98	ij	0.250	f	0.619	de
Dzc-3	1.18	fg	2.48	m	13.72	bc	28.17	b	7.46	j	90.65	h	0.194	n	0.575	k
Ylv-14	1.17	g	2.64	ij	14.80	a	25.10	e	27.25	a	165.71	b	0.186	p	0.628	c
Ylv-28	1.22	c	2.38	p	7.80	m	19.74	k	18.78	ı	97.83	g	0.236	h	0.625	cd
Ylv-31	1.19	ef	2.81	f	8.64	l	23.84	f	20.54	h	98.54	g	0.237	h	0.583	ij
Ylv-32	1.30	a	2.47	m	14.05	b	21.98	hı	18.78	ı	182.45	a	0.204	m	0.566	lm
Göynük-98	1.08	ı	2.75	g	14.05	b	21.80	ij	24.59	bc	48.98	n	0.181	q	0.581	j
Önceler-98	1.13	h	2.85	e	10.93	hı	26.85	c	21.11	gh	82.75	ij	0.228	ı	0.587	hı
Min	0.94		2.38		7.80		19.74		7.46		48.98		0.181		0.558	
Max	1.30		3.59		14.80		66.68		27.25		182.45		0.478		0.712	
Mean	1.14		2.75		11.77		25.84		19.48		100.92		0.242		0.605	
CV%	1.77		0.55		2.01		1.96		3.33		1.77		0.734		0.57	
LSD (0.05)	2.94		0.025		0.39		0.84		1.07		2.94		0.003		0.0057	

*CV: Coefficient of variation, LSD: Least significant difference.

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