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*Full Length Article*

# Micro and Macronutrients Diversity in Turkish Pea (*Pisum sativum*) Germplasm

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## Abstract

Field pea is very important pulse crop mainly cultivated in the temperate regions of the world. In the current study micro and macronutrients concentration was evaluated in the seeds of Turkish pea germplasm. Total 152 landraces and 5 commercial cultivars were collected from diverse geographic regions of Turkey. We found high diversity of nitrogen (N) (22.3–66.7 g $kg^{-1}$), phosphorus (P) (1.48–8.47 g $kg^{-1}$), potassium (K) (6.7–18.7 g $kg^{-1}$), iron (Fe) (38.6–320.9 mg $kg^{-1}$), zinc (Zn) (11.3–82.9 mg $kg^{-1}$), copper (Cu) (10.5–50.8 mg $kg^{-1}$) and manganese (Mn) (10.2–37.9 mg $kg^{-1}$) in Turkish pea germplasm. Average concentrations of N, P and Zn were observed higher in landraces while K, Fe, Cu and Mn concentration were found higher in commercial cultivars. Correlation among different mineral nutrients was positive and significant. Principal component analysis grouped the studied germplasm into two groups and first two principal components accounted about 56.88% of the total observed variations. Unweighted Pair Group Method with Arithmetic Mean (UPGMA) based clustering distinguished all germplasm according to their Mn concentration in pea seeds. Results from this study expressed a high range of diversity in the Turkish pea germplasm for micro and macronutrient elements. These findings will prove a valuable resource for the development of biofortified pea cultivars and varieties through conventional and modern breeding technologies and this intra variation could be used for identifying linked markers though genome wide association studies and identifying diverse parents for Quantitative trait locus (QTL) mapping. © 2018 Friends Science Publishers

**Keywords:** Biofortified pea; Nutrient diversity; Pea nutritional contents; Principal component analysis; Biofortification; Cluster analysis

## Introduction

Field pea (*Pisum sativum* L.) is one of the first domesticated crop and very important pulse of *Leguminosae* family, mainly grown in the temperate regions of the world. Archeological studies confirmed the existence of this crop back to 10,000 BC in central Asia (Riehl *et al*., 2013) and near East Asian regions (Zohary and Hopf, 2000). It is a self-pollinated diploid crop with 2n = 14 and genome size of 4.4 Gbps (Kaur *et al*., 2012). Pea is used for food in many ways and now it has become economically important legume crop along with the soybean, common bean, chickpea and peanut. Peas are very good source of protein (23–25%), carbohydrates and minerals like K, Fe, and calcium (Ca) (Meisrimler *et al*., 2017). Its seeds are full of nutrition and half of the world production of pea is used to feed the animals and rest are used for human consumption (Bangar *et al*., 2017). Seeds are a rich source of many essential amino acids like lysine and tryptophan that are present in very less concentration in cereal grains. Pea flour is receiving the attention of the world due to its unique nutritional qualities as peas usage in human and animal feed is universally accepted (Rodino *et al*., 2009). High nutritional value with low cost and easy availability makes it the food of choice and it is playing a major role to meet the dietary needs of 800–900 million people worldwide. Global field pea production was recorded 10.6 million tons mainly coming from Canada, USA, Europe and Russia (FAOSTAT, 2011) while it reached to 11332772 tons in the year 2013 with an area of 6 868 131 ha. In the year 2014, Canada leads the dry pea production by producing 30.4% of the world pea while other major countries were China (13.9%), Russia (13.3%), the United States (6.9%) and India (5.3%) (FAOSTAT, 2014).

Core pea genetic diversity area is broad that is expended from Fertile Crescent through Turkey, Syria, Lebanon, Iraq and Israel and is further expended to other countries such as Pakistan, Afghanistan, Turkmenistan and Iran (Smýkal *et al*., 2011). Turkey as a part of Fertile Crescent has served as the center of origin and genetic diversity of many wild and cultivated forms of woody, herbaceous, perennial and annual plants such as *Triticum*, *Cicer, Pisum, Lens, Hordeum, Avena, Beta, Allium, Prunus, Amygdalus, Secala, Vitis* and *Linum* spp. (Tan, 1998). In Turkey pea is grown on a large scale and considered an important part of Turkish diet (Baloch *et al*., 2015a). Based on the worldwide consumption, the pea is ranked as fourth leading legume crop while it is the second most important legume after common bean (*Phaseolus vulgaris* L.) in Turkey with a total production of 88,828 tons (FAOSTAT, 2008).

Biofortification is very important and efficient method aimed to improve the concentrations of various micronutrients, especially in the staple food crops through the combined application of classical breeding and modern biotechnological techniques (Graham *et al*., 2001; Nestel *et al*., 2006; Yasin *et al*., 2015). Well-balanced food is very important for the optimum growth of human being (Nestel *et al*., 2006; Gupta and Gupta, 2014; Naveen *et al*., 2016). These mineral elements take part in various body functions and well-balanced food having optimum concentrations of micro and macronutrients is the only source for human (White and Broadley, 2005; Murphy and Neumann, 2014). Our daily diet contains higher concentrations of protein, carbohydrates and many vitamins, however fails to provide recommended concentrations of Fe, Zn, and iodine (I). Moreover, some parts of the world also failed to provide sufficient amount of Ca, magnesium (Mg), Cu, and selenium (Se) (Welch and Graham, 2002; Prasad, 2013). Malnutrition of these micronutrients is also known as ‘‘hidden hunger’’ and has become a major public issue by affecting more than two billion people in the world (Frossard *et al*., 2000; Welch, 2002; Ruel-Bergeron *et al*., 2015). According to WHO (2011) more than 30% of the world’s population is facing Zn deficiency and 60% is facing Fe deficiency. Attempts were made in the past to solve the micronutrient malnutrition through food fortification, dietary diversification, and agronomic fortification, however, they failed in achieving optimum goals (White and Broadley, 2005; Hoekenga *et al*., 2011).

Although pea micro and macronutrient diversity has been elaborated in many reports mentioned earlier however, neither of the previous pea nutrient diversity studies focused on larger numbers of representative landraces present in Turkish farmer's field. Large-scale germplasms comprising of landraces remain poorly investigated in this regard. Furthermore, biofortification can serve as an alternative way to reduce the micro and macronutrients based malnutrition and peas are a great source of mineral nutrients. Hence in this study, we collected pea landraces present in farmer’s field from almost all available geographic locations of Turkey and explored the diversity of 7 mineral elements (N, P, K, Fe, Zn, Cu, and Mn). The results presented in this study can be used for the development of pea cultivars having high nutrients in Turkey and rest of the World and could attract international pea breeders interested in Turkish pea gene pool.

## Materials and Methods

### Plant Material and Crop Sowing

One hundred and fifty-two Turkish pea landraces and 5 commercial cultivars (Jof, Karina, Ulubatlı, Üzümlü and Kirazlı) collected from different provinces of Turkey were examined under this study. All Turkish pea landraces and 5 commercial cultivars were sown in 2016 on well-prepared seed bed using randomized block design with three replications at the Department of Crop and Animal Production, Vocational School of Sivas, Cumhuriyet University, Sivas (39.7505° N, 37.0150° E), Turkey. All landraces, cultivars and their collection sites are given in Table 1 and Fig. 1 shows the collection sites of Turkish pea germplasm used in this study. Landraces and cultivars were sown on a well-prepared plot (5 m long × 3.3 m wide) having four rows. Length of each row was 4 m and between two rows there was a distance of 50 cm and plant to plant distance was maintained at 10 cm. Drill sowing was performed by maintaining 50 plants in single row. Before sowing pea, soil samples were taken to determine some of the soil properties from 0–30 cm depth and were analyzed according to Page (1982). The soil was slightly alkaline (pH = 7.39), lime content was 17.1%, salinity level was low (0.32 ds $m^{-1}$), N and K concentrations were significant (0.11% and 1114.5 kg $ha^{-1}$, respectively) and P concentration was found low (42.4 kg $ha^{-1}$). Sowing of Turkish pea germplasm was performed on 16 March 2016 on well fertile clay loam soil. In the study, 40 kg $ha^{-1}$ N (N applied as ammonium sulfate) and 50 kg $ha^{-1}$ $P_2O_5$ (P applied as triple superphosphate) were applied with the drill as basic fertilization.

### Micro- and Macronutrients Analysis

Seeds for the micro and macronutrients analysis were selected from each landrace through the three-time random selection and were stored. These seeds were dried in an oven for 48 h at 65°C and then grounded for analysis. Concentrated $HNO_3$ (5 mL) and concentrated $H_2O_2$ (2 mL) were used for the digestion of grounded seed samples (0.2 g) in closed microwave digestion system (MARSxpress, CEM Corp. North Carolina, USA) and then an inductively coupled plasma optical emission spectrometer (ICP-OES; Vista-Pro Axial; Varian Pty Ltd., Australia) was used for the identification of mineral nutrient concentration in the Turkish pea germplasm. Total N was measured by the Kjeldahl method (Bremner, 1965). P was measured using spectrophotometer by following the method described by Jackson (1962). Concentrations of K, Cu, Fe, Mn and Zn were measured using atomic absorption spectrometry (Varian SpektrAA-300, Vienna, Austria) (Beaty and Kerber, 1993).

**Table 1:** Passport data of 152 landrace and 5 commercial cultivars of Turkish pea germplasm for different micro and macronutrient elements

| | Landraces/Varieties | Collection site | N (g kg$^{-1}$) | P (g kg$^{-1}$) | K (g kg$^{-1}$) | Fe (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Adana1 | Çukurköprü-Ceyhan | 39.9 ±0.15 | 2.45 ±0.25 | 10.8 ±0.12 | 38.6 ±1.11 | 29.2 ±0.92 | 11.0 ±0.50 | 14.4 ±0.78 |
| 2 | Adana2 | Doğankent | 37.1 ±0.13 | 2.68 ±0.08 | 9.2 ±0.17 | 47.0 ±0.42 | 30.8 ±0.55 | 10.5 ±0.35 | 14.6 ±0.62 |
| 3 | Adana3 | Kadirli | 34.1 ±0.18 | 5.67 ±0.12 | 12.3 ±0.14 | 44.8 ±0.35 | 37.6 ±0.60 | 11.3 ±0.40 | 14.9 ±0.76 |
| 4 | Adana4 | Kadirli | 42.1 ±0.32 | 2.74 ±0.06 | 8.2 ±0.11 | 75.9 ±2.32 | 47.5 ±2.78 | 13.5 ±9.70 | 19.9 ±2.01 |
| 5 | Adana5 | Ceyhan | 35.5 ±0.34 | 4.56 ±0.05 | 14.3 ±0.13 | 58.9 ±2.19 | 24.0 ±1.73 | 16.9 ±1.39 | 13.8 ±1.29 |
| 6 | Antalya1 | Kaş | 38.7 ±0.40 | 4.25 ±0.05 | 8.0 ±0.08 | 56.3 ±2.63 | 40.2 ±1.25 | 15.7 ±1.02 | 17.7 ±1.08 |
| 7 | Antalya2 | Finike | 44.1 ±0.85 | 3.34 ±0.06 | 17.2 ±0.15 | 55.2 ±1.64 | 15.8 ±2.07 | 16.0 ±1.53 | 12.4 ±1.21 |
| 8 | Antalya3 | Kale | 37.5 ±0.15 | 3.99 ±0.05 | 10.0 ±0.21 | 83.4 ±1.93 | 46.7 ±2.26 | 23.7 ±0.96 | 16.1 ±1.81 |
| 9 | Antalya4 | Kestel | 36.6 ±0.74 | 4.07 ±0.08 | 13.0 ±0.15 | 83.1 ±1.55 | 38.5 ±0.93 | 18.6 ±0.45 | 19.9 ±1.31 |
| 10 | Antalya5 | Kaş | 35.5 ±0.29 | 1.48 ±0.08 | 11.9 ±0.25 | 48.2 ±2.42 | 37.9 ±1.27 | 15.2 ±1.39 | 12.9 ±1.23 |
| 11 | Antalya6 | Kale | 38.6 ±0.25 | 4.70 ±0.13 | 14.8 ±0.19 | 43.6 ±0.56 | 35.9 ±0.27 | 13.4 ±0.31 | 15.7 ±0.46 |
| 12 | Antalya7 | Kestel | 39.6 ±0.11 | 3.46 ±0.20 | 12.3 ±0.07 | 45.7 ±0.50 | 46.9 ±0.47 | 11.8 ±0.75 | 16.6 ±0.71 |
| 13 | Antalya8 | Büyükbekiz | 44.7 ±0.10 | 4.30 ±0.16 | 12.7 ±0.12 | 56.6 ±0.67 | 50.2 ±1.24 | 13.4 ±0.46 | 14.2 ±0.35 |
| 14 | Antalya9 | Üzümlü | 39.8 ±0.32 | 3.80 ±0.15 | 9.6 ±0.11 | 49.2 ±0.70 | 43.8 ±0.80 | 13.0 ±1.35 | 15.5 ±0.56 |
| 15 | Antalya10 | Gazipaşa | 38.1 ±0.16 | 3.04 ±0.09 | 15.7 ±0.17 | 67.4 ±3.25 | 45.2 ±1.66 | 21.6 ±1.11 | 16.0 ±1.53 |
| 16 | Adıyaman1 | Aşağıçöplü | 40.3 ±0.29 | 4.35 ±0.15 | 8.1 ±0.22 | 49.2 ±0.62 | 37.8 ±0.69 | 13.0 ±0.56 | 14.0 ±0.71 |
| 17 | Adıyaman2 | Balkan | 36.6 ±0.26 | 3.15 ±0.13 | 14.1 ±0.09 | 125.1 ±1.75 | 62.5 ±1.01 | 17.3 ±0.46 | 15.1 ±0.71 |
| 18 | Adıyaman3 | Besni | 32.5 ±0.45 | 3.13 ±0.18 | 13.4 ±0.27 | 44.3 ±0.50 | 49.6 ±1.57 | 13.9 ±0.35 | 15.1 ±0.68 |
| 19 | Adıyaman4 | Adıyaman-Merkez | 37.2 ±0.14 | 3.04 ±0.06 | 10.6 ±0.26 | 53.6 ±0.75 | 48.5 ±1.16 | 16.1 ±0.57 | 15.1 ±0.31 |
| 20 | Afyon | Afyon-Merkez | 22.6 ±0.21 | 4.08 ±0.08 | 15.7 ±0.10 | 48.8 ±1.18 | 37.0 ±0.89 | 16.2 ±1.59 | 13.8 ±1.47 |
| 21 | Aydın1 | Ortaklar | 38.3 ±0.21 | 5.28 ±0.08 | 15.4 ±0.87 | 56.5 ±0.95 | 66.2 ±0.83 | 15.8 ±0.35 | 15.4 ±0.76 |
| 22 | Aydın2 | Ortaklar | 38.0 ±0.12 | 2.45 ±0.16 | 13.1 ±0.12 | 74.9 ±1.46 | 33.7 ±2.34 | 21.8 ±1.54 | 18.2 ±1.11 |
| 23 | Aydın3 | Ortaklar | 43.4 ±0.08 | 3.22 ±0.37 | 16.5 ±0.60 | 46.4 ±0.46 | 35.4 ±0.74 | 13.9 ±0.42 | 14.5 ±0.35 |
| 24 | Balıkesir1 | Burhaniye | 39.7 ±0.52 | 3.26 ±0.14 | 17.2 ±0.10 | 54.6 ±0.65 | 51.6 ±0.74 | 15.1 ±0.30 | 15.7 ±0.36 |
| 25 | Balıkesir2 | Paşaköy | 40.9 ±0.15 | 5.13 ±0.08 | 12.1 ±0.55 | 44.2 ±0.40 | 31.6 ±0.48 | 13.6 ±0.30 | 12.5 ±0.56 |
| 26 | Balıkesir3 | Burhaniye | 34.1 ±0.38 | 2.14 ±0.05 | 7.1 ±0.11 | 78.4 ±1.25 | 32.1 ±1.91 | 18.9 ±1.44 | 20.4 ±1.59 |
| 27 | Balıkesir4 | Balıkesir-Merkez | 28.0 ±0.25 | 4.27 ±0.28 | 18.5 ±0.10 | 44.0 ±0.42 | 39.9 ±1.02 | 16.4 ±0.85 | 12.5 ±0.46 |
| 28 | Bingöl | Bingöl | 28.7 ±0.38 | 4.43 ±0.04 | 17.3 ±0.10 | 68.5 ±1.76 | 51.8 ±1.62 | 24.1 ±1.12 | 13.8 ±1.49 |
| 29 | Burdur | Burdur | 34.9 ±0.25 | 4.12 ±0.06 | 11.0 ±0.21 | 61.7 ±1.29 | 63.9 ±1.44 | 22.4 ±0.87 | 14.7 ±1.33 |
| 30 | Bolu | Yeniçağa | 37.5 ±0.84 | 4.36 ±0.70 | 13.7 ±0.14 | 62.4 ±0.91 | 56.9 ±1.74 | 21.5 ±2.31 | 14.9 ±1.31 |
| 31 | Bursa1 | Orhaneli | 39.5 ±0.21 | 1.85 ±0.04 | 14.2 ±0.11 | 73.2 ±1.73 | 19.3 ±1.27 | 20.4 ±1.47 | 15.9 ±1.47 |
| 32 | Bursa2 | Firuz | 34.0 ±0.34 | 4.29 ±0.27 | 15.8 ±0.10 | 48.7 ±0.72 | 42.9 ±0.28 | 14.9 ±0.21 | 14.9 ±0.35 |
| 33 | Bursa3 | Gelemiş | 28.1 ±0.24 | 5.34 ±0.12 | 16.9 ±0.08 | 43.2 ±0.79 | 35.6 ±1.12 | 18.3 ±1.02 | 10.8 ±0.57 |
| 34 | Bursa4 | Bursa-Merkez | 42.0 ±0.12 | 4.48 ±0.25 | 15.3 ±0.19 | 43.7 ±1.17 | 43.0 ±1.27 | 14.7 ±0.76 | 14.5 ±0.93 |
| 35 | Bursa5 | Mürseller | 37.3 ±0.59 | 1.86 ±0.14 | 11.0 ±0.24 | 54.7 ±2.21 | 29.4 ±1.78 | 16.8 ±0.75 | 12.4 ±1.06 |
| 36 | Bursa6 | Kalkan | 39.8 ±0.25 | 3.57 ±0.07 | 9.9 ±0.35 | 87.8 ±2.08 | 53.7 ±1.21 | 27.8 ±1.97 | 21.3 ±1.11 |
| 37 | Bursa7 | Muradiye | 35.0 ±0.25 | 4.70 ±0.05 | 11.5 ±0.19 | 48.0 ±1.38 | 16.2 ±1.30 | 15.1 ±1.25 | 13.3 ±2.04 |
| 38 | Bursa8 | Mürseller | 44.1 ±0.63 | 3.27 ±0.12 | 11.1 ±0.22 | 48.8 ±0.87 | 53.8 ±2.18 | 15.9 ±0.21 | 19.2 ±1.45 |
| 39 | Çanakkale1 | İntepe | 42.0 ±0.44 | 3.84 ±0.04 | 11.6 ±0.45 | 79.0 ±1.43 | 64.7 ±1.28 | 20.0 ±1.33 | 21.2 ±2.34 |
| 40 | Çanakkale2 | Bahçecik | 34.9 ±0.08 | 3.08 ±0.16 | 12.9 ±0.14 | 51.0 ±1.16 | 53.9 ±1.50 | 13.9 ±1.21 | 15.9 ±1.19 |
| 41 | Çanakkale3 | Yenice | 42.2 ±0.19 | 3.75 ±0.20 | 13.4 ±0.11 | 61.4 ±0.91 | 63.6 ±2.32 | 17.1 ±1.50 | 14.6 ±1.48 |
| 42 | Denizli1 | Denizli | 29.6 ±0.09 | 2.71 ±0.06 | 13.8 ±0.10 | 84.3 ±0.95 | 54.0 ±1.41 | 26.3 ±1.59 | 14.5 ±0.83 |
| 43 | Denizli2 | Burhaniye | 31.6 ±0.20 | 2.12 ±0.04 | 13.0 ±0.57 | 82.7 ±1.47 | 38.9 ±2.51 | 24.1 ±1.55 | 18.8 ±1.96 |
| 44 | Denizli3 | Denizli-Merkez | 38.4 ±0.28 | 4.12 ±0.07 | 13.0 ±0.68 | 49.8 ±1.02 | 43.8 ±0.35 | 12.5 ±0.91 | 14.5 ±0.96 |
| 45 | Diyarbakır | Diyarbakır | 37.7 ±0.10 | 3.10 ±0.08 | 11.9 ±0.15 | 64.2 ±1.23 | 40.5 ±0.75 | 15.1 ±1.35 | 15.1 ±0.93 |
| 46 | Edirne1 | Alıç | 37.5 ±0.32 | 2.03 ±0.06 | 15.0 ±0.41 | 52.1 ±1.14 | 52.7 ±0.77 | 16.6 ±0.74 | 13.7 ±1.69 |
| 47 | Edirne2 | Alıç | 39.0 ±0.45 | 3.50 ±0.11 | 8.8 ±0.14 | 55.0 ±1.46 | 24.3 ±1.23 | 16.1 ±1.51 | 12.8 ±1.59 |
| 48 | Elazığ | Elazığ-Merkez | 32.9 ±0.14 | 5.39 ±0.29 | 15.4 ±0.22 | 154.8 ±2.56 | 82.9 ±3.51 | 50.8 ±1.04 | 37.9 ±1.23 |
| 49 | Gaziantep1 | KirliAlici | 30.2 ±0.17 | 4.89 ±0.34 | 15.6 ±0.35 | 43.4 ±0.59 | 33.2 ±1.47 | 14.3 ±1.14 | 12.7 ±1.04 |
| 50 | Gaziantep2 | Kilis | 34.2 ±0.11 | 2.20 ±0.08 | 11.9 ±0.10 | 51.7 ±0.90 | 32.9 ±1.92 | 15.0 ±0.76 | 15.1 ±1.51 |
| 51 | Giresun | Keşap | 34.9 ±0.21 | 3.32 ±0.07 | 16.2 ±0.21 | 247.8 ±7.10 | 44.2 ±1.17 | 22.1 ±0.93 | 18.6 ±0.51 |
| 52 | Hakkari | Alan | 33.6 ±0.74 | 5.89 ±0.20 | 16.3 ±0.31 | 49.9 ±1.08 | 38.2 ±1.49 | 18.9 ±1.23 | 13.9 ±0.96 |
| 53 | Hatay1 | Hassaya | 36.8 ±0.21 | 5.41 ±0.08 | 17.4 ±0.10 | 46.3 ±0.57 | 43.1 ±0.18 | 13.0 ±0.25 | 11.8 ±0.31 |
| 54 | Hatay2 | Kırıkhan | 33.9 ±0.12 | 5.06 ±0.06 | 18.7 ±0.24 | 59.8 ±2.00 | 57.9 ±1.47 | 19.4 ±0.89 | 14.2 ±0.91 |
| 55 | Hatay3 | Serinyol | 30.1 ±0.54 | 4.55 ±0.10 | 13.3 ±0.10 | 77.5 ±2.67 | 47.7 ±0.91 | 18.7 ±0.86 | 15.4 ±1.10 |
| 56 | Isparta | Eğirdir | 38.5 ±0.14 | 5.51 ±0.03 | 14.2 ±0.31 | 75.0 ±1.54 | 50.6 ±1.60 | 20.7 ±2.06 | 17.4 ±1.17 |
| 57 | İstanbul | İstanbul-Merkez | 32.9 ±0.74 | 3.99 ±0.13 | 16.1 ±0.14 | 54.8 ±1.79 | 39.3 ±0.83 | 15.0 ±0.79 | 13.6 ±0.62 |
| 58 | İzmir1 | Bağyurdu | 34.5 ±0.12 | 4.98 ±0.28 | 12.4 ±0.11 | 49.7 ±2.06 | 38.9 ±1.19 | 13.8 ±1.48 | 16.5 ±0.85 |
| 59 | İzmir2 | YenikuruDere | 35.2 ±0.80 | 5.05 ±0.27 | 13.8 ±0.13 | 90.1 ±1.40 | 75.3 ±2.70 | 26.0 ±0.75 | 15.2 ±0.87 |
| 60 | İzmir3 | Orhanlı | 42.7 ±0.51 | 3.45 ±0.10 | 13.9 ±0.17 | 81.0 ±1.87 | 42.2 ±0.99 | 23.3 ±1.59 | 16.2 ±1.23 |
| 61 | İzmir4 | İzmir | 35.6 ±0.11 | 3.46 ±0.04 | 13.0 ±0.74 | 183.5 ±4.05 | 51.4 ±2.18 | 19.0 ±0.46 | 19.9 ±1.78 |
| 62 | K. Maraş | Torun | 41.8 ±0.36 | 3.00 ±0.11 | 15.4 ±0.21 | 53.4 ±0.97 | 37.8 ±2.04 | 16.1 ±1.15 | 14.7 ±2.26 |
| 63 | Karaman | Yeşildere | 46.3 ±0.32 | 2.97 ±0.07 | 15.5 ±0.14 | 45.8 ±0.89 | 42.6 ±1.30 | 16.8 ±0.46 | 13.9 ±1.83 |
| 64 | Kars | Kaş | 41.3 ±0.65 | 3.17 ±0.37 | 9.3 ±0.11 | 49.7 ±1.95 | 60.9 ±0.31 | 14.3 ±1.10 | 13.6 ±1.21 |
| 65 | Kastamonu | İnebolu-Pazar | 27.8 ±0.10 | 3.83 ±0.23 | 8.5 ±0.08 | 50.3 ±1.61 | 40.2 ±1.38 | 14.9 ±0.72 | 11.9 ±0.76 |

**Table 1:** Continued

**Table 1:** Continued

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | Kırklareli1 | Akçaköy | 42.0 | ±0.32 | 5.87 | ±0.25 | 11.1 | ±0.25 | 58.7 | ±2.08 | 56.1 | ±1.52 | 16.0 | ±0.85 | 16.5 | ±1.78 |
| 67 | Kırklareli2 | Vize – Kıyıköy | 35.1 | ±0.39 | 3.44 | ±0.16 | 8.5 | ±0.31 | 40.4 | ±1.70 | 31.8 | ±1.37 | 13.0 | ±0.86 | 11.0 | ±0.80 |
| 68 | Konya1 | TorosDağları | 26.1 | ±0.44 | 3.72 | ±0.03 | 12.0 | ±0,85 | 50.6 | ±2.29 | 40.5 | ±1.73 | 15.0 | ±1.15 | 14.1 | ±1.25 |
| 69 | Konya2 | Konya | 37.2 | ±0.29 | 3.05 | ±0.10 | 13.1 | ±0.37 | 51.9 | ±0.95 | 41.0 | ±1.75 | 16.4 | ±1.14 | 14.8 | ±1.27 |
| 70 | Konya3 | Konya | 40.5 | ±0.32 | 3.61 | ±0.05 | 14.9 | ±0.44 | 157.5 | ±2.38 | 72.6 | ±1.99 | 20.8 | ±1.63 | 15.8 | ±1.42 |
| 71 | Manisa1 | Muradiye | 39.5 | ±0.25 | 4.95 | ±0.09 | 16.0 | ±0.79 | 97.4 | ±0.56 | 57.9 | ±1.49 | 28.7 | ±2.03 | 15.4 | ±1.14 |
| 72 | Manisa2 | Avşar | 31.3 | ±0.64 | 4.20 | ±0.12 | 14.4 | ±0.14 | 49.1 | ±1.74 | 34.5 | ±2.03 | 14.8 | ±1.25 | 15.4 | ±1.14 |
| 73 | Manisa3 | Kınık | 35.6 | ±0.85 | 2.93 | ±0.03 | 12.3 | ±0.10 | 60.1 | ±1.53 | 39.4 | ±1.76 | 17.9 | ±1.39 | 15.4 | ±1.07 |
| 74 | Manisa4 | Kınık | 42.3 | ±0.24 | 2.78 | ±0.06 | 14.0 | ±1.29 | 91.7 | ±3.22 | 73.7 | ±1.41 | 40.8 | ±1.18 | 24.6 | ±2.66 |
| 75 | Manisa5 | Manisa | 28.6 | ±0.17 | 4.79 | ±0.17 | 18.7 | ±0.10 | 62.9 | ±2.27 | 52.3 | ±1.05 | 21.6 | ±0.82 | 15.1 | ±1.31 |
| 76 | Manisa6 | Kınık | 42.3 | ±0.74 | 2.67 | ±0.06 | 13.0 | ±0.88 | 87.5 | ±2.01 | 62.6 | ±1.15 | 25.8 | ±2.16 | 19.9 | ±0.92 |
| 77 | Manisa7 | Turgutlu | 37.1 | ±0.54 | 3.21 | ±0.03 | 15.4 | ±0.27 | 50.4 | ±1.63 | 20.3 | ±1.45 | 15.2 | ±1.31 | 11.5 | ±1.07 |
| 78 | Mardin | Kızıltepe - Viranşehir | 30.0 | ±0.10 | 1.94 | ±0.04 | 6.7 | ±0.34 | 46.5 | ±0.70 | 44.0 | ±1.66 | 14.8 | ±1.28 | 14.0 | ±0.56 |
| 79 | Mersin1 | Fındıkpınarı | 37.0 | ±0.32 | 3.50 | ±0.03 | 12.2 | ±0.12 | 53.3 | ±1.14 | 48.1 | ±1.34 | 16.1 | ±1.33 | 13.2 | ±0.85 |
| 80 | Mersin2 | Gazipaşa | 40.3 | ±0.31 | 3.57 | ±0.17 | 14.2 | ±0.14 | 99.8 | ±1.76 | 70.2 | ±1.11 | 24.9 | ±1.27 | 15.2 | ±1.48 |
| 81 | Mersin3 | Gülnar | 35.0 | ±1.11 | 3.91 | ±0.29 | 13.6 | ±0.19 | 53.8 | ±0.92 | 43.3 | ±0.72 | 16.5 | ±0.91 | 13.5 | ±0.93 |
| 82 | Mersin4 | Aydıncık | 42.0 | ±0.58 | 3.24 | ±0.05 | 14.8 | ±0.21 | 62.4 | ±0.89 | 47.5 | ±2.08 | 18.8 | ±1.29 | 15.8 | ±1.44 |
| 83 | Mersin5 | Fındıkpınarı | 23.7 | ±0.65 | 5.55 | ±0.16 | 17.3 | ±0.10 | 49.5 | ±1.78 | 37.7 | ±2.03 | 14.4 | ±0.91 | 13.8 | ±1.51 |
| 84 | Mersin6 | Yenice | 36.6 | ±0.32 | 4.99 | ±0.21 | 11.8 | ±0.27 | 49.6 | ±1.63 | 35.1 | ±1.41 | 17.2 | ±1.17 | 18.7 | ±1.08 |
| 85 | Mersin7 | Yenice | 36.3 | ±0.74 | 3.87 | ±0.07 | 15.8 | ±0.31 | 63.1 | ±0.40 | 41.7 | ±1.51 | 19.8 | ±0.93 | 16.9 | ±1.03 |
| 86 | Mersin8 | Toros Mountains | 37.8 | ±0.71 | 3.71 | ±0.05 | 14.5 | ±0.14 | 88.9 | ±2.15 | 41.4 | ±1.33 | 19.7 | ±1.59 | 17.4 | ±0.91 |
| 87 | Mersin9 | Yenice | 38.3 | ±0.36 | 3.81 | ±0.06 | 12.0 | ±0.48 | 69.9 | ±1.51 | 30.4 | ±1.64 | 19.6 | ±1.17 | 15.7 | ±3.54 |
| 88 | Mersin10 | Fındıkpınarı | 38.2 | ±0.14 | 3.08 | ±0.04 | 11.4 | ±0.32 | 105.3 | ±3.69 | 46.3 | ±1.74 | 21.4 | ±2.25 | 26.1 | ±1.47 |
| 89 | Muğla1 | Üzümlü | 24.8 | ±0.07 | 6.14 | ±0.21 | 18.2 | ±0.10 | 49.8 | ±1.25 | 50.7 | ±1.50 | 17.7 | ±1.19 | 16.4 | ±1.95 |
| 90 | Muğla2 | Esen | 28.0 | ±0.41 | 5.21 | ±0.06 | 14.4 | ±0.98 | 45.9 | ±1.59 | 33.2 | ±1.83 | 14.8 | ±0.95 | 11.8 | ±1.51 |
| 91 | Muğla3 | Ula | 22.3 | ±0.74 | 3.52 | ±0.02 | 13.0 | ±1.02 | 39.0 | ±1.50 | 31.4 | ±1.12 | 14.3 | ±1.00 | 12.2 | ±1.97 |
| 92 | Muğla4 | Pazar | 37.5 | ±0.25 | 4.68 | ±0.04 | 13.4 | ±0.10 | 53.3 | ±1.46 | 43.6 | ±1.17 | 17.0 | ±1.61 | 14.0 | ±1.87 |
| 93 | Ordu | Gülyalı | 36.6 | ±0.95 | 4.42 | ±0.13 | 13.7 | ±0.15 | 50.9 | ±0.95 | 48.0 | ±1.31 | 18.5 | ±0.76 | 14.7 | ±1.78 |
| 94 | Sakarya1 | Adapazarı | 27.7 | ±0.82 | 4.27 | ±0.03 | 10.8 | ±0.30 | 52.4 | ±1.08 | 47.8 | ±1.22 | 15.8 | ±1.44 | 17.2 | ±0.95 |
| 95 | Sakarya2 | Adapazarı | 35.0 | ±0.31 | 3.40 | ±0.11 | 9.2 | ±0.10 | 51.7 | ±1.29 | 40.4 | ±1.57 | 14.1 | ±1.42 | 16.6 | ±1.21 |
| 96 | Sinop | Erfelek | 35.0 | ±0.69 | 3.62 | ±0.08 | 16.1 | ±0.16 | 54.2 | ±1.64 | 44.9 | ±1.76 | 17.6 | ±1.59 | 12.8 | ±1.40 |
| 97 | Sivas | Tokat-Sivas 12.km | 33.4 | ±0.23 | 4.39 | ±0.11 | 15.5 | ±0.24 | 53.1 | ±1.16 | 35.7 | ±1.43 | 17.5 | ±1.25 | 14.1 | ±0.87 |
| 98 | Ş. Urfa | Pirhallı | 42.0 | ±0.35 | 3.28 | ±0.08 | 12.7 | ±0.16 | 56.1 | ±1.11 | 53.3 | ±0.95 | 18.2 | ±1.57 | 14.7 | ±0.78 |
| 99 | Şırnak | Silopi | 32.2 | ±0.31 | 3.35 | ±0.08 | 15.6 | ±0.11 | 48.1 | ±1.32 | 34.8 | ±1.22 | 16.2 | ±1.38 | 14.0 | ±1.55 |
| 100 | Tekirdağ1 | Emirali | 38.8 | ±0.24 | 8.47 | ±0.20 | 9.2 | ±0.17 | 59.0 | ±1.30 | 49.8 | ±1.27 | 15.1 | ±1.71 | 16.4 | ±1.14 |
| 101 | Tekirdağ2 | Kumbağ - Gaziköy | 40.8 | ±0.26 | 3.93 | ±0.04 | 11.9 | ±0.22 | 320.9 | ±6.65 | 60.1 | ±1.39 | 25.5 | ±1.27 | 17.8 | ±2.06 |
| 102 | Tekirdağ3 | Kumbağ - Gaziköy | 43.6 | ±0.91 | 2.18 | ±0.06 | 12.9 | ±0.31 | 50.0 | ±1.95 | 29.9 | ±1.36 | 16.3 | ±1.29 | 11.0 | ±0.86 |
| 103 | Tekirdağ4 | Uçmakdere | 45.4 | ±0.18 | 5.74 | ±0.04 | 15.0 | ±0.24 | 97.9 | ±1.37 | 75.1 | ±1.32 | 24.8 | ±1.22 | 17.0 | ±1.48 |
| 104 | Tekirdağ5 | Çerkezkoy | 39.0 | ±0.24 | 4.77 | ±0.08 | 14.9 | ±0.41 | 70.6 | ±1.69 | 73.3 | ±1.09 | 21.5 | ±1.02 | 17.0 | ±1.01 |
| 105 | Tekirdağ6 | Hayrabolu | 35.4 | ±0.28 | 4.20 | ±0.05 | 9.6 | ±0.35 | 61.9 | ±1.53 | 40.0 | ±1.08 | 16.6 | ±1.08 | 18.1 | ±1.38 |
| 106 | Tekirdağ7 | Mermer | 42.5 | ±0.64 | 4.13 | ±0.03 | 12.4 | ±0.22 | 68.1 | ±1.48 | 48.6 | ±1.89 | 18.3 | ±1.07 | 14.1 | ±0.91 |
| 107 | Tekirdağ8 | Naip | 31.6 | ±0.35 | 2.63 | ±0.05 | 12.4 | ±0.12 | 54.8 | ±2.33 | 41.9 | ±1.45 | 21.8 | ±1.06 | 15.5 | ±1.21 |
| 108 | Tekirdağ9 | Hayrabolu | 33.8 | ±0.10 | 2.88 | ±0.08 | 8.2 | ±0.17 | 69.8 | ±1.52 | 44.7 | ±1.41 | 18.0 | ±0.61 | 15.5 | ±1.12 |
| 109 | Tekirdağ10 | Ortaca | 31.5 | ±0.05 | 3.98 | ±0.06 | 13.1 | ±0.14 | 69.6 | ±1.89 | 34.6 | ±2.10 | 20.0 | ±0.61 | 15.1 | ±0.85 |
| 110 | Tekirdağ11 | Paşaköy | 39.2 | ±0.38 | 5.33 | ±0.10 | 12.0 | ±0.11 | 68.8 | ±2.72 | 34.9 | ±1.32 | 18.4 | ±0.92 | 16.2 | ±0.75 |
| 111 | Tokat1 | Niksar | 24.1 | ±0.63 | 3.98 | ±0.08 | 10.0 | ±0.19 | 119.1 | ±3.70 | 48.0 | ±1.37 | 18.5 | ±1.87 | 16.0 | ±1.98 |
| 112 | Tokat2 | Almus | 24.1 | ±0.36 | 6.40 | ±0.40 | 16.7 | ±0.28 | 60.1 | ±1.29 | 43.3 | ±1.17 | 19.2 | ±1.23 | 14.0 | ±1.42 |
| 113 | Tokat3 | Niksar | 34.5 | ±0.32 | 2.95 | ±0.11 | 10.5 | ±0.19 | 46.1 | ±1.57 | 27.8 | ±1.16 | 15.3 | ±1.44 | 11.6 | ±1.08 |
| 114 | Bursa | Firuz | 45.5 | ±0.13 | 2.50 | ±0.05 | 12.7 | ±0.12 | 84.7 | ±2.15 | 43.6 | ±2.28 | 22.8 | ±1.47 | 19.5 | ±1.83 |
| 115 | Muğla1 | Esen | 44.0 | ±0.65 | 2.00 | ±0.04 | 11.7 | ±0.57 | 89.7 | ±1.73 | 34.8 | ±2.08 | 21.9 | ±1.72 | 19.6 | ±1.74 |
| 116 | Muğla2 | Esen | 35.3 | ±0.70 | 2.00 | ±0.04 | 12.0 | ±0.14 | 71.8 | ±2.52 | 35.3 | ±1.80 | 18.3 | ±1.64 | 17.6 | ±2.52 |
| 117 | Çanakkale | Bahçecik | 40.6 | ±0.41 | 5.45 | ±0.09 | 15.8 | ±0.11 | 75.2 | ±1.90 | 39.4 | ±1.03 | 18.8 | ±1.14 | 15.5 | ±1.86 |
| 118 | *Not applicable(e.g., breeding material or unknown) | | 40.4 | ±0.41 | 3.28 | ±0.04 | 10.7 | ±0.19 | 51.1 | ±0.82 | 29.8 | ±1.70 | 16.1 | ±0.51 | 16.7 | ±1.07 |
| 119 | *Not applicable(e.g., breeding material or unknown) | | 34.5 | ±0.63 | 2.85 | ±0.13 | 13.8 | ±0.11 | 46.6 | ±1.35 | 22.9 | ±1.48 | 16.8 | ±1.23 | 12.3 | ±1.21 |
| 120 | *Not applicable(e.g., breeding material or unknown) | | 39.3 | ±0.21 | 3.22 | ±0.04 | 13.8 | ±0.24 | 48.2 | ±1.61 | 23.0 | ±1.20 | 14.7 | ±1.33 | 11.8 | ±1.28 |
| 121 | *Not applicable(e.g., breeding material or unknown) | | 59.9 | ±0.04 | 3.16 | ±0.03 | 12.8 | ±0.13 | 46.4 | ±1.85 | 20.0 | ±1.28 | 15.6 | ±1.04 | 13.8 | ±1.27 |
| 122 | *Not applicable(e.g., breeding material or unknown) | | 40.1 | ±0.49 | 3.85 | ±0.10 | 10.3 | ±0.14 | 47.1 | ±1.67 | 23.1 | ±1.55 | 14.1 | ±1.61 | 12.7 | ±1.78 |
| 123 | *Not applicable(e.g., breeding material or unknown) | | 32.9 | ±0.63 | 4.35 | ±0.09 | 12.9 | ±0.11 | 46.9 | ±1.37 | 18.2 | ±1.51 | 15.6 | ±1.51 | 13.2 | ±1.33 |
| 124 | *Not applicable(e.g., breeding material or unknown) | | 34.7 | ±0.25 | 2.89 | ±0.08 | 13.7 | ±0.09 | 46.2 | ±1.70 | 18.1 | ±0.94 | 15.2 | ±1.31 | 12.4 | ±1.16 |
| 125 | *Not applicable(e.g., breeding material or unknown) | | 39.7 | ±0.26 | 3.17 | ±0.15 | 11.9 | ±0.14 | 47.5 | ±1.81 | 19.5 | ±0.65 | 14.5 | ±1.15 | 11.5 | ±1.12 |
| 126 | *Not applicable(e.g., breeding material or unknown) | | 41.7 | ±0.27 | 5.14 | ±0.05 | 13.1 | ±0.62 | 53.3 | ±1.10 | 30.6 | ±1.69 | 17.4 | ±0.91 | 12.9 | ±1.23 |
| 127 | *Not applicable(e.g., breeding material or unknown) | | 27.0 | ±0.45 | 2.72 | ±0.03 | 13.2 | ±0.10 | 44.1 | ±1.70 | 11.8 | ±1.18 | 14.3 | ±1.01 | 12.5 | ±1.80 |
| 128 | *Not applicable(e.g., breeding material or unknown) | | 38.9 | ±0.31 | 3.47 | ±0.07 | 9.1 | ±0.17 | 47.6 | ±1.14 | 27.4 | ±1.25 | 14.5 | ±1.03 | 13.0 | ±1.49 |

**Table 1:** Continued

**Table 1:** Continued

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 129 | *Not applicable (e.g., breeding material or unknown) | 46.5 | ±0.85 | 3.65 | ±0.06 | 10.8 | ±0.21 | 39.0 | ±1.51 | 11.3 | ±0.70 | 13.7 | ±1.39 | 10.2 | ± |
| 130 | *Not applicable (e.g., breeding material or unknown) | 35.1 | ±0.61 | 2.23 | ±0.05 | 13.5 | ±0.29 | 77.9 | ±1.86 | 42.6 | ±0.70 | 17.4 | ±1.19 | 21.4 | ± |
| 131 | *Not applicable (e.g., breeding material or unknown) | 34.7 | ±0.32 | 3.16 | ±0.09 | 12.0 | ±0.31 | 93.5 | ±1.06 | 70.1 | ±2.28 | 21.3 | ±1.12 | 17.6 | ± |
| 132 | *Not applicable (e.g., breeding material or unknown) | 39.7 | ±0.35 | 2.63 | ±0.07 | 13.8 | ±0.14 | 84.0 | ±0.81 | 41.3 | ±1.43 | 20.6 | ±1.94 | 16.9 | ± |
| 133 | *Not applicable (e.g., breeding material or unknown) | 27.8 | ±0.21 | 3.17 | ±0.04 | 11.5 | ±0.12 | 82.2 | ±2.12 | 27.1 | ±0.95 | 14.3 | ±1.03 | 20.0 | ± |
| 134 | *Not aplicable (e.g., breeding material or unknown) | 38.7 | ±0.54 | 2.42 | ±0.03 | 10.7 | ±0.19 | 65.9 | ±1.36 | 28.9 | ±1.28 | 16.8 | ±1.25 | 15.9 | ± |
| 135 | *Not aplicable (e.g., breeding material or unknown) | 40.7 | ±0.37 | 3.00 | ±0.07 | 13.8 | ±0.20 | 84.8 | ±2.18 | 46.9 | ±1.13 | 21.1 | ±1.95 | 17.8 | ± |
| 136 | *Not aplicable (e.g., breeding material or unknown) | 38.9 | ±0.46 | 2.49 | ±0.04 | 16.2 | ±0.30 | 73.9 | ±1.31 | 32.1 | ±1.12 | 18.0 | ±1.39 | 17.0 | ± |
| 137 | *Not aplicable (e.g., breeding material or unknown) | 34.0 | ±0.23 | 3.27 | ±0.05 | 16.3 | ±0.14 | 90.0 | ±1.32 | 47.8 | ±2.10 | 22.2 | ±1.72 | 17.8 | ± |
| 138 | *Not aplicable (e.g., breeding material or unknown) | 29.8 | ±0.29 | 2.22 | ±0.03 | 14.2 | ±0.16 | 73.9 | ±1.61 | 32.3 | ±1.23 | 19.3 | ±1.68 | 16.6 | ± |
| 139 | *Not aplicable (e.g., breeding material or unknown) | 39.5 | ±0.84 | 2.50 | ±0.05 | 12.9 | ±0.45 | 72.1 | ±1.97 | 43.0 | ±1.53 | 20.6 | ±1.93 | 23.4 | ± |
| 140 | *Not aplicable (e.g., breeding material or unknown) | 35.4 | ±0.47 | 2.76 | ±0.07 | 13.6 | ±0.17 | 71.3 | ±2.46 | 24.3 | ±1.73 | 19.3 | ±1.82 | 16.7 | ± |
| 141 | *Not aplicable (e.g., breeding material or unknown) | 40.0 | ±0.08 | 2.51 | ±0.08 | 13.3 | ±0.14 | 80.2 | ±1.23 | 49.3 | ±3.14 | 20.1 | ±1.39 | 18.7 | ± |
| 142 | *Not aplicable (e.g., breeding material or unknown) | 36.4 | ±0.74 | 2.83 | ±0.07 | 10.5 | ±0.11 | 70.9 | ±1.57 | 35.2 | ±1.73 | 20.3 | ±1.48 | 16.3 | ± |
| 143 | *Not aplicable (e.g., breeding material or unknown) | 66.7 | ±0.39 | 3.75 | ±0.08 | 13.0 | ±0.19 | 81.4 | ±1.35 | 44.7 | ±2.35 | 22.9 | ±1.11 | 18.4 | ± |
| 144 | *Not aplicable (e.g., breeding material or unknown) | 36.0 | ±0.41 | 3.54 | ±0.12 | 11.7 | ±0.13 | 81.3 | ±1.12 | 25.4 | ±1.81 | 18.7 | ±1.18 | 18.2 | ± |
| 145 | *Not aplicable (e.g., breeding material or unknown) | 34.4 | ±0.25 | 4.19 | ±0.07 | 11.4 | ±0.14 | 71.1 | ±1.12 | 28.0 | ±1.40 | 21.3 | ±1.20 | 15.4 | ± |
| 146 | *Not aplicable (e.g., breeding material or unknown) | 29.8 | ±0.28 | 2.27 | ±0.03 | 18.5 | ±0.12 | 74.7 | ±2.11 | 23.2 | ±1.63 | 19.5 | ±1.80 | 16.1 | ± |
| 147 | *Not aplicable (e.g., breeding material or unknown) | 32.3 | ±0.16 | 2.00 | ±0.05 | 15.0 | ±0.47 | 65.5 | ±2.59 | 25.0 | ±2.21 | 19.0 | ±1.10 | 15.5 | ± |
| 148 | *Not aplicable (e.g., breeding material or unknown) | 32.9 | ±0.09 | 2.18 | ±0.15 | 13.5 | ±0.20 | 77.4 | ±2.83 | 35.7 | ±2.20 | 22.1 | ±1.74 | 18.0 | ± |
| 149 | *Not aplicable (e.g., breeding material or unknown) | 37.5 | ±0.32 | 2.87 | ±0.08 | 10.8 | ±0.23 | 76.6 | ±2.00 | 39.1 | ±1.25 | 22.9 | ±1.65 | 18.1 | ± |
| 150 | *Not aplicable (e.g., breeding material or unknown) | 40.8 | ±0.41 | 5.26 | ±0.06 | 11.8 | ±0.41 | 97.8 | ±2.10 | 62.3 | ±1.08 | 27.1 | ±1.51 | 19.8 | ± |
| 151 | *Not aplicable (e.g., breeding material or unknown) | 36.4 | ±0.28 | 3.67 | ±0.07 | 14.2 | ±0.16 | 83.3 | ±1.01 | 41.2 | ±1.17 | 24.2 | ±1.10 | 20.5 | ± |
| 152 | *Not aplicable (e.g., breeding material or unknown) | 37.5 | ±0.25 | 2.49 | ±0.04 | 12.1 | ±0.40 | 77.4 | ±2.54 | 39.1± | ±1.53 | 22.9 | ±1.46 | 18.2 | ± |
| | **Commercial Varieties** | | | | | | | | | | | | | | |
| 153 | Jof | 41.1 | ±0.65 | 2.98 | ±0.08 | 11.9 | ±0.15 | 73.4 | ±1.93 | 36±.6 | ±1.16 | 19.8 | ±2.14 | 16.2 | ± |
| 154 | Karina | 32.8 | ±0.36 | 2.68 | ±0.09 | 13.7 | ±0.14 | 76.8 | ±1.97 | 25.7 | ±2.76 | 21.3 | ±1.27 | 18.5 | ± |
| 155 | Ulubatlı | 34.2 | ±0.49 | 4.50 | ±0.07 | 15.8 | ±0.19 | 87.7 | ±2.89 | 37.2 | ±2.23 | 26.3 | ±2.33 | 20.9 | ± |
| 156 | Üzümlü | 36.8 | ±0.19 | 1.96 | ±0.08 | 12.9 | ±0.10 | 66.8 | ±2.26 | 43.6 | ±1.14 | 20.6 | ±2.18 | 19.3 | ± |
| 157 | Kirazlı | 27.0 | ±0.11 | 3.85 | ±0.06 | 18.4 | ±0.15 | 61.6 | ±2.59 | 28.0 | ±1.39 | 20.5 | ±1.12 | 20.0 | ± |

*Breeding material or unknown

## Statistical Analysis

Analysis of variance was performed for 7 traits by using the PROC GLM method of SAS computer program. Significant variation (*P*<0.01) was identified between the accessions for all studied traits. For the investigation of various mineral characteristics, standard deviation (SDs) was also calculated. Diversity pattern of 7 mineral nutrients elements was determined through the principal component analysis (PCA) using the JMP statistical software. PROC CORR (SAS program) was performed for correlation among 7 studied traits. To group the landraces and cultivars on the basis of studied traits, a cluster analysis, and PCA was performed based on the Euclidean distances and unweighted pair group method with arithmetic mean (UPGMA) was applied (Rohlf, 2004; Raza *et al*., 2017).

## Results

Total 152 Turkish pea landraces and 5 commercial cultivars were collected from different geographical regions of Turkey (Table 1). Table 2 represents the mean, maximum, minimum and standard deviations (SD) values of all analyzed variables in 152 pea landraces and 5 cultivars. Landraces and commercial cultivars exhibited significant differences for all observed morphological traits and also expressed prominent variations in different mineral levels. On the dry weight basis, mean N concentration in landraces was 36.7 g $kg^{-1}$ with 66.7 g $kg^{-1}$ as maximum and 22.3 g $kg^{-1}$ minimum values. The concentration of N in cultivars was in ranged between 41.1 g $kg^{-1}$ and 27.0 g $kg^{-1}$ with an average of 34.38 g $kg^{-1}$. The concentration of P in studied Turkish pea germplasm varied between 1.48 to 8.47 g $kg^{-1}$ having 3.68 g $kg^{-1}$ as an average P concentration. The maximum value for K concentration was recorded as 18.7 g $kg^{-1}$ and 6.7 g $kg^{-1}$ as the minimum value with 13.1 g $kg^{-1}$ as a mean K concentration.

Micronutrients expressed significant variations in the studied Turkish pea germplasm. Fe concentration in the seeds of Turkish pea germplasm varied strongly with a range between 38.6 mg $kg^{-1}$ to 320.9 mg $kg^{-1}$ averaging 67.9 mg $kg^{-1}$. Mean Zn concentration in the studied material was 41.68 mg $kg^{-1}$ and ranged between 11.3 mg $kg^{-1}$ to 82.9 mg $kg^{-1}$. While Cu concentration in Turkish pea germplasm was found in the range of 10.5 mg $kg^{-1}$ to 50.8 mg $kg^{-1}$ with an average of 18.29 mg $kg^{-1}$. Mean Mn concentration in this studied germplasm was recorded 15.7 mg $kg^{-1}$ with 10.2 mg $kg^{-1}$ and 37.9 mg $kg^{-1}$ minimum and maximum concentrations. During this study, N, P and Zn mean concentrations were observed higher in landraces as compared to cultivars. While mean K, Fe, Cu and Mn concentrations were expressed higher in cultivars as compared to landraces. The maximum and minimum N, P, K and micronutrients concentrations were within a wide range as compared to commercial cultivars that expressed a narrow range for all studied mineral elemental traits.

**Table 2:** List of the 7 quality descriptors utilized in this study with variety adjusted means associated, standard deviations (SD) and ranges

| | Landraces | | | | Cultivars | | | |
|---|---|---|---|---|---|---|---|---|
| Nutrient Content | Mean | SD | Range | | Mean | SD | Range | |
| | | | Min | Max | | | Min | Max |
| N (g kg$^{-1}$) | 36.6982 | 5.92 | 22.30 | 66.70 | 34.3867 | 5.19 | 27.00 | 41.10 |
| P (g kg$^{-1}$) | 3.6844 | 1.11 | 1.47 | 8.47 | 3.1959 | 0.99 | 1.96 | 4.50 |
| K (g kg$^{-1}$) | 13.1013 | 2.51 | 6.70 | 18.70 | 14.5400 | 2.59 | 11.90 | 18.40 |
| Fe (mg kg$^{-1}$) | 67.9132 | 33.83 | 38.63 | 320.9 | 73.2733 | 9.98 | 61.63 | 87.73 |
| Zn (mg kg$^{-1}$) | 41.6817 | 13.71 | 11.28 | 82.93 | 34.2053 | 7.29 | 25.68 | 43.57 |
| Cu (mg kg$^{-1}$) | 18.2916 | 4.91 | 10.53 | 50.80 | 21.7000 | 2.62 | 19.83 | 26.30 |
| Mn (mg kg$^{-1}$) | 15.7852 | 3.26 | 10.23 | 37.86 | 18.9800 | 1.76 | 16.23 | 20.86 |

**Table 3:** Correlation coefficient among different micro and macro nutrients for Turkish pea landraces

| | N | P | K | Fe | Zn | Mn | Cu |
|---|---|---|---|---|---|---|---|
| N | 1 | | | | | | |
| P | -0.58 | 1 | | | | | |
| K | -0.145** | 0.223** | 1 | | | | |
| Fe | 0.032 | -0.006 | 0.069 | 1 | | | |
| Zn | 0.138** | 0.243** | 0.085 | 0.415** | 1 | | |
| Mn | 0.025 | -0.003 | 0.197** | 0.606** | 0.479** | 1 | |
| Cu | 0.055 | -0.084 | -0.042 | 0.550** | 0.408** | 0.667** | 1 |

** Significant at $P$<0.01


**Fig. 1:** Collection sites of 152 landraces and 5 commercial cultivars of Turkish pea germplasm for different micro- and macro-nutrient elements

Table 3 represents the correlation among the 7 mineral elements in the 152 Turkish pea landraces and 5 commercial cultivars. The positive and highly significant correlation was found among various mineral elements. Most nutrients were positively correlated with each other during this study and they increased the power of the test. So only values of 0.1 or above are discussed in this study. Fe (r =0.415 $P$<0.01) showed a positive and highly significant correlation with Zn, Mn, and Cu. Zn expressed significant and positive correlation with N (r = 0.138 $P$<0.01), P (r = 0.243 $P$<0.01) and Fe (r =0.415 $P$<0.01). Similarly, Mn showed positive and significant correlation with K (r = 0.197 $P$<0.01), Fe (r =606 $P$<0.01) and Zn (r = 0.479 $P$<0.01). We witnessed that Cu had positive correlation with Fe (r =0.550 $P$<0.01), Zn (r = 0.479 $P$<0.01) and Mn (r = 0.667 $P$<0.01).

For the determination of diversity within the panel of 152 Turkish pea landraces and 5 commercial cultivars, PCA analysis was performed for all 7 mineral traits. We investigated eigenvalues, variations percentage and load coefficient of first six components for all seven mineral traits through the application of PCA based on the correlation matrix. During this study, accessions expressed a consistent and wide range of variation for the all 7 investigated traits as a result of PCA. On the basis of the correlation coefficient, applied PCA revealed that first six principal components resulted in 96.17% of the cumulative variance (Table 4 and Fig. 3). The pattern of variations among the studied material was investigated by drawing a graph using first two PCA (Fig. 3). Among these six principal components, first principal component (PC1) was very important because it contains more than 1 third of total variation. Cu played a lead role in PC1 followed by the Mn, Fe and Zn, respectively. Second principal component (PC2) explained a total of 20.22% variation with P as a leading mineral element. Third principal component (PC3) showed a greater dependence on the N and PC3 accounted 13.41% of total variability. Among these six principal components, first two were very important and contributed more than half (56.88%) of the total variation.

Cluster analysis was performed to investigate the relationship between the landraces and commercial cultivars. Association among 152 landraces and 5 commercial cultivars of Turkish pea germplasm were revealed by UPGMA cluster analysis based on Euclidian distance coefficients for 7 micro and macronutrient elements (Fig. 2 and Table 5). UPGMA based clustering divided the studied material into two main groups A and B. Group A contains 46 landraces and 4 commercial cultivars (Karina, Ulubatlı, Üzümlü and Kirazlı). Group B is a larger group as compared to group A and contains 106 landraces with only 1 commercial cultivar Jof (Fig. 2 and Table 5). The whole studied material was collected from different geographical regions of Turkey and UPGMA based clustering confirms the presence of extensive diversity among the Turkish pea germplasm.

## Discussion

Biodiversity served as a source of genetic improvement and also can play an important role for the improvement of nutritional quality, productivity and adaptation in the economically important crops (Van Der Heijden *et al*., 2016; Baloch *et al*., 2017). Identification of genetic variations for the mineral elements present in low concentration and their application in breeding helped the human being to improve the nutrient qualities in various crops (White and Broadley, 2005; Baloch *et al*., 2015b). Biofortification and plant breeding together can play handful role in the improvement of important essential elements and their bioavailable form in the plant food.

**Table 4:** Eigenvectors, eigenvalues, individual and cumulative percentages of variation explained by the first six principal components (PC) after assessing quality traits in Turkish pea landraces

| Eigenvectors | | | | | | |
|---|---|---|---|---|---|---|
| Variables | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
| N (g $kg^{-1}$) | 0.10213 | -0.43368 | 0.71252 | 0.52843 | 0.03592 | 0.11524 |
| P (g $kg^{-1}$) | 0.04354 | 0.61334 | 0.53374 | -0.33291 | 0.12731 | 0.45639 |
| K (g $kg^{-1}$) | 0.08444 | 0.59262 | -0.19175 | 0.73391 | -0.06337 | -0.00462 |
| Fe (mg $kg^{-1}$) | 0.46510 | -0.08695 | -0.18597 | 0.01609 | 0.85461 | 0.07032 |
| Zn (mg $kg^{-1}$) | 0.45752 | 0.19782 | 0.31745 | -0.17856 | -0.10224 | -0.77302 |
| Cu (mg $kg^{-1}$) | 0.54465 | 0.02808 | -0.15433 | 0.10595 | -0.27606 | 0.17730 |
| Mn (mg $kg^{-1}$) | 0.50820 | -0.19247 | -0.10724 | -0.16714 | -0.40182 | 0.38008 |
| Eigenvalue | 2.566 | 1.415 | 0.938 | 0.800 | 0.544 | 0.466 |
| Percent | 36.66 | 20.22 | 13.41 | 11.43 | 7.776 | 6.662 |
| Cumulative percentages | 36.66 | 56.88 | 70.29 | 81.73 | 89.51 | 96.17 |

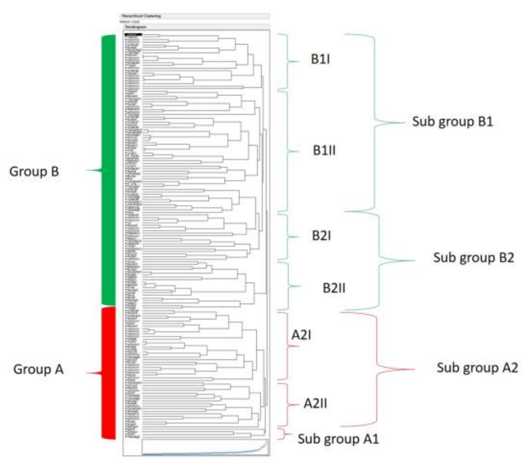


**Fig. 2:** UPGMA based clustering of 152 landraces and 5 commercial cultivars of Turkish pea germplasm

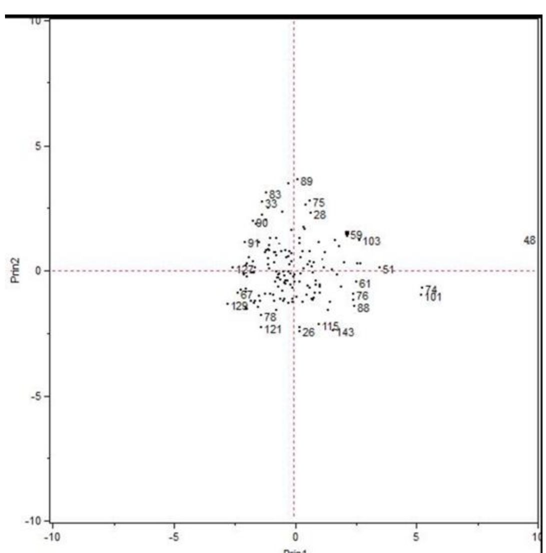


**Fig. 3:** Multivariate PCA of 152 landraces and 5 commercial cultivars of Turkish pea germplasm

The effectiveness of classical breeding methods can be effectively applied with the precise biotechnological techniques for the improvement of various deficient mineral elements like Zn, Fe, Cu, and Mn in the human diet (Nestel *et al*., 2006). Many efforts have been made to improve the mineral elements concentration through the biofortification and plant breeding in various crops such as wheat (Velu *et al*., 2015), maize (Pillay *et al*., 2013), faba bean (Baloch *et al*., 2014; Karaköy *et al*., 2014) and lentil (Karaköy *et al*., 2012).

Landraces act as a source of genetic diversity are crop populations containing specific ecology or geographic representation and developed under the influence of cultural and local environment (Hagenblad *et al*., 2012). Nutritional improvement in any crop can be achieved through the characterization of these landraces. A huge portion of world's population is directly affected by the mineral deficiencies in the diet (Welch, 2002; Ruel-Bergeron *et al*., 2015). Legumes are a good source of various essential nutrients and they can be very helpful to meet human food demands with greater nutritional quality (Wang *et al*., 2003). Additionally, pulses provide good concentrations of various mineral elements, vitamins and many secondary metabolites that are necessary for optimum human growth (Cannon *et al*., 2009).

One hundred and fifty two pea landraces and 5 commercial cultivars were collected from different locations of Turkey during this study in order to investigate the mineral concentration in these landraces and cultivars (Table 1). The main theme of this study was to evaluate the concentrations of some macronutrients (N, P, K) and micronutrients (Zn, Fe, Cu, Mn) in the seeds of Turkish pea germplasm. Significant variations for all 7 mineral elements were observed in the pea landraces. For the different mineral element concentrations, landraces and cultivars behaved differently. For example, maximum values of N, P, and Zn were found nearly two times greater in landraces as compared to commercial cultivars. Previous studies have also shown the greater concentrations of these nutrients in landraces as compared to cultivars in pea and other legume crops (Amarakoon *et al*., 2012; Baloch *et al*., 2014). This great variation for the concentrations of different mineral elements present in the Turkish pea germplasm can be used as a source in the pea nutritional improvement breeding stratagems. For example huge variation of Fe (38.6–320.9 mg $kg^{-1}$) was observed in the landraces that express the presence of higher Fe concentration in pea and can be used in the development of cultivars having higher bioavailable Fe contents. These landraces were collected from various geographical and environmental regions of Turkey (Fig. 1) that also contributed in the mineral concentration variations. Similarly landraces with higher concentrations of different mineral elements can be used to investigate the accumulation and transportation of these micro and macronutrients (Karaköy *et al*., 2012).

**Table 5:** Dendogram grouping of Turkish pea germplasm

| Main cluster | Sub cluster | Total no of Accessions | Accessions |
|---|---|---|---|
| A | Subgroup A1 | 4 | Tekrdag2, Izmir4, Giresun, Elazag |
| | Subgroup A2 A2I | 28 | Antalya4, Mersin8, Antalya10, Mersin7, Unknown, Izmir3, Mersin4, Unknown, Unknown, Unknown, Unknown, Ulubatli, Aydin2, Unknown, Mugla2,Uzumlu, Denizli2, Unknown, Tekirdağ8, Denizli1, Bursa1, Unknown, Unknown, Unknown, Unknown, Karina, Unknown, Kirazli |
| Total | A2II | 18 50 | Adiyaman2, Konya3, Mersin2, Unknown, Izmir2, Tekirdağ5, Tekirdağ4, Manisa1, Bursa6, Unknown, Çanakkale1, Manisa6, Mersin10, Unknown, Unknown, Bursa, Mugla1, Manisa4 |
| B | Subgroup B1 | | |
| | B1I | 22 | Adana1, Adana2, Unknown, Unknown, Antalya5, Bursa5, Gaziantep2, Tekirdağ3, Edirne2, Unknown, Unknown, Kırklareli2, Tokat3, Unknown, Antalya2, Manisa7, Unknown, Unknown, Unknown, Unknown, Unknown, Unknown |
| | B1II | 48 | Adana3, Izmir1, Mersin6, Tekirdağ11, Adana5, Bursa7, Unknown, Balıkesir2, Unknown, Tekirdağ1, Antalya6, Bursa4, Antalya7, Denizli3, Antalya8, Adiyaman3,Çanakkale2, Diyarbakir, Konya2, Manisa3, Mersin1, Mersin3, Mugla4, Ordu, Aydin3, K.Maras, Karaman, Balıkesir1, Edirne1, Aydin1, , Kırklareli1, Isparta, Çanakkale, Burdur, Bolu, Çanakkale3, S.urfa, Tekirdağ7, Adana4, Bursa8, Antalya1, Tekirdağ6, Antalya9, Adiyaman1, Adiyaman4, Sakarya2, Tekirdağ9, Kars |
| | Subgroup B2 | | |
| | B2I | 18 | Antalya3, Unknown, Unknown, Jof, Mersin9, Unknown, Unknown, Balıkesir3, Unknown, Hatay3, Tekirdağ10, Sakarya1, Tokat1, Kastamonu, Mardin, Konya1, Mugla3, Unknown, |
| Total | B2II | 19 107 | Afyon, Mersin5, Balıkesir4, Bursa3, Gaziantep1, Mugla2, Hakkari1, Hatay1, Bursa2, Istanbul, Sivas, Manisa, Sirnak, Sinop, Bingol, Manisa5, Hatay2, Mugla1, Tokat2 |

While genotypes, seed composition, seed characteristics, soil conditions, agronomic activities, environmental factors and some other factors can also produce the variations in the chemical composition (Baloch *et al*., 2014).

Average N, P and Zn concentrations were found higher in landraces as compared to cultivars. Landrace 143 reflected maximum concentration of N as compared to other landraces and cultivars. Similarly, Tekirdağ-1 was the landrace in which higher concentration of P was recorded. In this study, we found a higher concentration of Zn in Elazığ Landrace. Interestingly the average concentrations of K, Fe, Cu, and Mn were found higher in cultivars as compared to landrace while the maximum concentration of these minerals was recorded in landraces. Higher concentrations of K were present in Hatay2 and Manisa5 landraces. Tekirdağ2 landrace resulted in higher Fe concentration which was almost 4 folds greater than in the other cultivars. The maximum concentration of Cu and Mn was recorded in Elazığ landrace. Elazığ landrace had higher concentrations of micronutrients like Zn, Cu, and Mn, so this landrace can be a promising resource for the improvement of micronutrient concentrations in pea germplasm. Similarly, landraces from Tekirdağ exhibited higher P and Fe concentrations, suggesting their possible inclusion in pea breeding programs. These findings are in line with the previous report on mineral concentration in peas by Amarakoon *et al*. (2012).

Multivariate analysis are mainly performed for the investigation of variations in a germplasm and to identify the relative contributions that are added by various traits in the total variability of crop germplasm collection. Such types of analysis are helpful in the classification of germplasm entries according to their similar traits. From the spatial distribution of landraces, however, it has been possible to identify 'superior' accessions of some traits with such types of analysis. In this study, Multivariate analysis reflected the movement of some landraces (same numerical sequence in Table 1) away from the center of axix, thus representing unique diversity from the other landraces (Fig. 3). These landraces reflected great source of variarions for the studied mineral elements and could be used as direct source for the breeding of Turkish pea germplasm. Applied PCA revealed that first six principal components resulted in 96.17% of the cumulative variance (Table 4). However, first two PCAs played a dominating role and we found Cu and P in lead role in both PCAs respectively. We observed synergistic effects between the different nutrients and according to the previous study this effect may be due to the presence of similar transporters or pathways, controlling the transportation and uptake of these nutrient elements (Karaköy *et al*., 2012). Mn showed a highly significant and positive correlation with K, Fe, and Zn. While positive and highly significant correlation was observed between Cu, Fe, Zn, and Mn. According to a previous study, a higher concentration of Zn may be correlated with the higher concentration of other micronutrients (Karaköy *et al*., 2012). In our study, landraces with higher Zn concentration also showed higher concentrations of other nutrients. Ray *et al*. (2014) also investigated higher concentrations of Zn, Fe, Cu and Mn, in field pea, and greatly supported our findings i.e. occurrence of higher concentrations of these mineral nutrients in studied material.

Fig. 2 and Table 5 represents the UPGMA based clustering of Turkish pea germplasm. All germplasm was grouped into two main groups A (red) and B (green) mainly on the basis of Mn concentrations in their seeds (Fig. 2). A total of 50 genotypes grouped in to the group A and this group was further subdivided into A1 and A2 subgroups. Subgroup A1 was further subdivided and it contained only 4 landraces. Elazig, Giresun, Izmir4 and Tekirdag2 were the landraces grouped in the A1 sub cluster (Table 5). All these landraces clustered in the subgroup A1 also contains higher concentrations of Fe due to their positive correlation with Mn and landrace Tekirdag2 contained the highest concentration of Fe (320.9 mg $kg^{-1}$) among the all studied landraces and cultivars. Subgroup A2 was also further subdivided into two subgroups i.e., A2I and A2II. Subgroup A2I was further grouped in too many subgroups and contained 4 commercial cultivars and 24 landraces. Similarly, subgroup A2II was also further subdivided and contains 18 landraces.

UPGMA based clustering divided the main group B into two subgroups B1 and B2 and a total of 106 landraces and only 1 commercial cultivar (Jof) grouped in this main B group (Table 5). The B1 subgroup contained a total of 70 genotypes and was further subdivided into B1I and B1II. Subgroup B1I was further sub grouped and it contained 22 landraces. Subgroup B1II was also further sub grouped and it contains 48 landraces and only one commercial cultivar (Jof) having similar concentrations of Mn. Main subgroup B2 contained a total of 37 genotypes and was also further sub grouped into B2I and B2II. A total of 18 and 19 landraces grouped in the B2I and B2II groups respectively (Table 5). During this study, a positive correlation of Mn was also observed with Fe and the same pattern of correlation was observed by Karaköy *et al*. (2012) in faba bean. Cluster analysis showed the presence of accessions from different geographical regions in each group which suggested that there was no clear kinship between the genetic diversity and accessions and thus revealed that the diversity of pea collected from various geographical regions of Turkey is not uniform. Therefore, for the improvement in the Turkish pea germplasm, landraces should be focused not their geographical location for the source of diversity (Karaköy *et al*., 2014). Interestingly, four out of the 5 studied cultivars (Karina, Ulubatlı, Üzümlü and Kirazlı) were clustered in subgroup A2I showing a high resemblance or a low level of diversity. While commercial cultivar Jof clustered in subgroup B1II and showed a higher level of diversity and can be used in future pea breeding programs. DNA markers has revolutionized the breeding of crops through the application of efficient and precise techniques like QTL mapping and genome wide association studies (GWAS) (Nadeem *et al*., 2017). We selected and selfed single plant from each landrace and future research will be focused on association mapping of the various mineral elements by using these selfed genotypes. This will helps to identify the loci responsible for the increased mineral elements in the Turkish pea germplasm, which will be handful in the development of Pea cultivar with improved mineral concentrations.

## Conclusion

Turkey harbored unique place in Fertile Crescent that is the Cradle of Agriculture for many agricultural crops such as major cereals and legumes including pea. Information about pea germplasm diversity and screening germplasm for useful agronomic and quality traits, resistance against different biotic and abiotic stress would promote preservation, management of this species, Therefore we had provided the information about diversity for important micro-macronutrients critical for human health in Turkish pea gene pool and we have to make strategies for preserving this precious gene pool for securing food for our future generations. Many international agencies such as Biodiversity international and Food and agricultural organization of the world as well as Turkish government already started ex-site and *in situ* large scale germplasm conservation especially in the south eastern Turkey. We investigated significant variations in the concentrations of various micro and macronutrients in the Turkish pea germplasm (152 landraces and five commercial cultivars). The presented results are a good resource for the development of biofortified pea cultivars. This would in turn play an important role to overcomes the dietary deficiencies. Variation investigated in our study can be used for the identification of linked markers for various traits of interest and identified markers could be converted into Kompetitive Allele Specific PCR (KASP) assays for the more precise pea breeding programs. This study provides the basic knowledge about the variation of different mineral elements concentrations; however, there is need to conduct such experiments under the various environmental conditions for several years. Results of this would be very beneficial for the breeders and researchers not only in Turkey but also from any part of the world who are interested in Turkish pea germplasm.

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