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## The Effects of Zinc Application on Zinc Efficiency and Nutrient Composition of Lentil (*Lens culinaris* Medic.) Cultivars

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**Abstract:** Effects of five different Zn application rates (0, 0.5, 1.0, 1.5 and 2.0 kg Zn da<sup>-1</sup>) on Zn efficiency and nutrient composition of three lentil cultivars, Sazak-91 (S-91), Yerli kırmızı (YK) and Kışlık kırmızı-51 (KK-51), were determined in the Zn deficient field conditions during the 1998-99 and 1999-00 cropping seasons. The highest grain yields for the cultivars were obtained at the highest Zn application rate. Grain yields of the cultivars increased with increasing Zn application rates in order KK-51 < YK < S-91 in both the cropping seasons. Regardless of the differences in the cultivars, average relative yield of lentil at non-fertilized application increased from 71% in 1998-99 to 76% in 1999-00. Drought conditions caused decreases in the Zn uptake and Zn efficiency of the cultivars in the first year compared to the second year. Zn efficiency of the cultivars increased with increasing Zn fertilization rates in order KK-51 < YK < S-91. Among the cultivars YK was the most sensitive to Zn deficiency under drought conditions. Zn uptake and Zn concentration of the cultivars were usually increased at 1.0 and 1.5 kg Zn da<sup>-1</sup> application rates. Generally, Zn concentration of the cultivars gave the positive correlations with N and K concentration and negative correlations with P, Fe and Mn concentrations. Relationship between Zn and Cu concentrations was more variable.

**Key words:** Lentil cultivars, nutrient composition, zinc fertilization

### INTRODUCTION

Zinc (Zn) deficiency is one of the most important mineral consumption problems among human beings, animals and plants. All organs, tissues and fluids in the mammalian body contain Zn<sup>[1]</sup>. The concentration of zinc in the adult human body is about 0.46 mmol kg<sup>-1</sup> body weight<sup>[2]</sup>. It has been reported that more than two billion people in the world are influenced by the deficiencies of Zn, Fe, I and vitamin A<sup>[3,4]</sup>. There is zinc deficiency in the 30% of the cultivated soil in the world, particularly in arid and semi-arid regions<sup>[5,6]</sup>. Zinc deficiency decreases nutritional quality of cereal grain and contributes the health problems in human beings, especially in the developing countries<sup>[7,4]</sup>. Çakmak *et al.*<sup>[8]</sup> reported that Zn deficiency, generally cereal growing areas of Turkey, is a critical nutritional problem for plants and humans. There is zinc deficiency about 50% of the cultivated soils in Turkey<sup>[9]</sup>. The major factor for the zinc deficiency in soils is the low availability of Zn to plant rather than its content in soils and restricting conditions of zinc efficiency for plants are high pH, high lime content, low organic matter and low moisture content in soil<sup>[10,11]</sup>.

Rengel *et al.*<sup>[12]</sup> reported that fertilization with inorganic and organic forms of micronutrients has a potential to increase their concentrations in grain and the most effective fertilization could be via soil (for Zn and to some extent, Cu), foliarly (for Fe) and by adding fertilizers to the irrigation water (for iodine). Quantities of minerals in edible portions of crops are influenced by numerous complex, dynamic and interacting factors, including plant genotype, soil properties, environmental conditions and nutrient interactions<sup>[13]</sup>. It has been known that crop species have differing micronutrient density in grain when grown under similar conditions<sup>[12]</sup>. In the study by Parker<sup>[14]</sup>, the relative sensitivity of six crop species to low Zn was found as maize>tomato>wheat>alfalfa~ tall wheatgrass>soybean. Zinc efficiency among the cereal species has been reported to decline as follow rye>triticale>barley>bread wheat>oat>durum wheat<sup>[15,16]</sup>. In the study by Brennan *et al.*<sup>[17]</sup>, the yield and Zn content response of cool-season grain legumes and wheat to applications of Zn fertilizer was compared in a glasshouse experiment using two alkaline soils from SW Australia. They found that the Zn requirement was lowest for faba bean and increased in order faba bean< chickpea <wheat<lentil.

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Zinc deficiency is a widespread problem in crop plants, especially cereals<sup>[18]</sup>. Zinc concentration of legumes, especially beans, is one of the highest among vegetable sources<sup>[19]</sup>. The objectives of this study were to determine the effects of different zinc application rates on Zn efficiency and nutrient concentrations in grains of three different lentil cultivars under Zn deficient field conditions.

## MATERIALS AND METHODS

Field experiments during the 1998-1999 and 1999-2000 cropping seasons were carried out in the experimental field of Agricultural Faculty in Yüzüncü Yıl University, Van which is located at 38.5°N and 43.3°E of SE Turkey. Total annual precipitation and average temperature values were 250 mm and 7.8°C in the 1998-1999 and 280 mm and 6.2°C in the 1999-2000 cropping season, respectively<sup>[20]</sup>. Some physical and chemical properties of soil samples taken from 0 to 20 cm depth were determined as follows: particle size distribution by Bouyocous hydrometer method<sup>[21]</sup>, lime content by Scheibler Calsimeter<sup>[22]</sup>, soil reaction, pH in 1:2.5 (w:v) soil:water suspension by pH meter and soil salinity by EC meter in the same suspension<sup>[23]</sup>; organic matter content by Walkley-Black method<sup>[24]</sup>, exchangeable cations by ammonium acetate extraction<sup>[25]</sup>; available phosphorus by Olsen's method<sup>[26]</sup>; DTPA extractable heavy metals (Fe, Mn, Zn, Cu) according to Lindsay and Norvel<sup>[27]</sup>.

The field experiments were conducted in a factorial randomized complete block design with three replications in each cropping season. Seeds were obtained from the different organizations as follows; Sazak-91 (S-91) from Transitional Zone Agricultural Research Station – Eskişehir, Yerli Kırmızı (YK) from Southeast Agricultural Research Station – Diyarbakır and Kışlık Kırmızı-51 (KK-51) from Agricultural Faculty of Ankara University. After fall plowing and rototilling (5 cm deep) of soil, plots (1x5 m<sup>2</sup>) were sown to three lentil cultivars (*Lens culinaris* Medic.), S-91, YK and KK-51 in October 24, 1998 and October 28, 1999. Lentil cultivars were seeded in rows 1 m apart and seeding rate was 350 seeds m<sup>-2</sup>. Two meters space was left unplanted between the blocks. Regarding the different Zn contents of zinc sulphate (ZnSO<sub>4</sub>.7H<sub>2</sub>O), five different zinc rates of ZnSO<sub>4</sub>.7H<sub>2</sub>O were applied to soil as 0 (control), 0.5, 1.0, 1.5 and 2.0 kg Zn da<sup>-1</sup> and incorporated into soil by disk-plowing in just prior to planting. At planting, 2.0 kg N da<sup>-1</sup> and 4.0 kg P da<sup>-1</sup> were top-dressed in the form of ammonium sulphate (21% N) and triple superphosphate (42% P<sub>2</sub>O<sub>5</sub>), respectively. Crops in each season were harvested at the maturity state in June 26, 1999 and July 2, 2000. Grains were sampled to determine grain yield and nutrient concentration.

Grain samples were washed in deionized water and then oven-dried at 75°C for 48 h. After grinding the samples, they were digested in a mixture of nitric and perchloric acid (4:1 HNO<sub>3</sub>:HClO<sub>4</sub>) and analyzed for phosphorous (P) spectrophotometrically and potassium (K), zinc (Zn) iron (Fe), manganese (Mn) and copper (Cu) using atomic absorption spectrophotometer according to Kacar<sup>[28]</sup>. Total nitrogen contents in the ground samples were determined by the Kjeldahl method<sup>[29]</sup>.

Statistical analysis of experimental data was accomplished by standard analysis of variance and pairs of mean values compared by least significant difference (LSD) using the SAS software package<sup>[29]</sup>.

## RESULTS

Some physical and chemical properties of soil taken from 0-20 cm depth in the experimental field are given in Table 1. The results can be summarized as; the textural class of soil is sandy loam, slightly alkaline in pH, low in organic matter, very slightly saline according to EC value<sup>[30]</sup>. DTPA-extractable Zn concentration in soil was lower than the widely accepted critical Zn concentration of 0.5 mg kg<sup>-1</sup><sup>[31]</sup>.

The effects of Zn application rates on grain yield of three lentil cultivars in 1998-99 and 1999-00 cropping seasons are given in Fig. 1. The grain yield of all cultivars in both cropping seasons significantly increased at  $p < 0.05$  with increasing the Zn application rates. The highest increments in grain yields were obtained at the highest Zn application rate. In 1998-99 cropping season, grain yields with Zn application ranged from 74.5 kg da<sup>-1</sup> for Sazak-91 at the 2.0 kg Zn da<sup>-1</sup> rate to 34.1 kg da<sup>-1</sup> for Kışlık kırmızı-51 at the control application, resulting in average yield of 50.67 kg da<sup>-1</sup>. In 1999-00 cropping season, grain yields ranged from 79.2 kg da<sup>-1</sup> for S-91 at the 2.0 kg Zn da<sup>-1</sup> rate to 43.5 kg da<sup>-1</sup> for KK-51 at the control application, with an average yield of 62.03 kg da<sup>-1</sup>. The highest yielding cultivars in both cropping seasons were increased in order Kışlık kırmızı-51 < Yerli kırmızı < Sazak-91. Increases in average yields of S-91, YK and KK-51 from first to second cropping season were obtained as 8.9, 35.6

Table 1: Some physical and chemical properties of the soil

|   |       |                                 |       |
|---|-------|---------------------------------|-------|
| Sand, %                                     | 62.60 | NH <sub>4</sub> OAc extractable |       |
| Silt, %                                     | 17.50 | K, g kg <sup>-1</sup>           | 0.29  |
| Clay, %                                     | 19.90 | Ca, g kg <sup>-1</sup>          | 2.65  |
| EC <sub>25°C</sub> , mmhos cm <sup>-1</sup> | 0.77  | Mg, g kg <sup>-1</sup>          | 0.24  |
| pH  | 8.54  |                                 |       |
| Organic matter, %                           | 0.44  | DTPA extractable                |       |
| CaCO <sub>3</sub> , %                       | 3.68  | Fe, mg kg <sup>-1</sup>         | 6.80  |
| Total N, g kg <sup>-1</sup>                 | 1.10  | Cu, mg kg <sup>-1</sup>         | 1.20  |
| Olsen P, mg kg <sup>-1</sup>                | 31.20 | Zn, mg kg <sup>-1</sup>         | 0.37  |
|   |       | Mn, mg kg <sup>-1</sup>         | 11.40 |

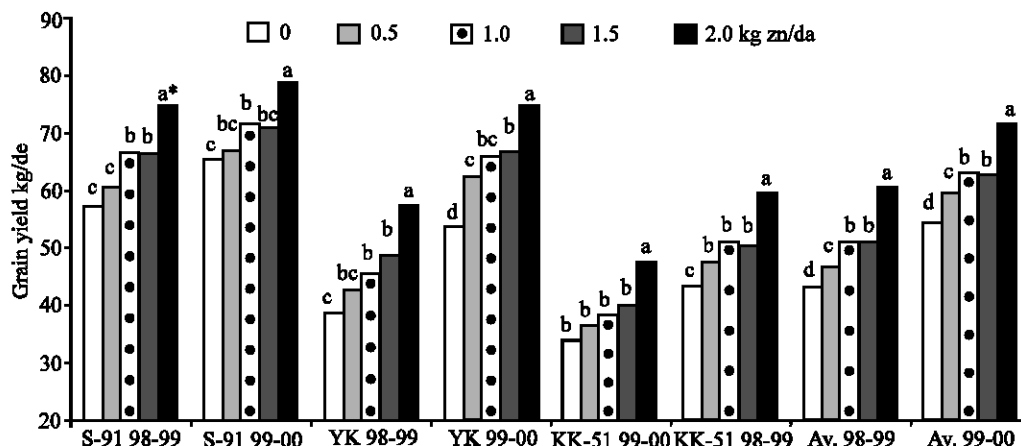


Fig. 1: Effects of different Zn application rates on grain yield of Sazak-91 (S-91), Yerli Kırmızı (YK), Kışlık kırmızı-51 (KK-51) lentil cultivars and the average yields of lentil during the 1998-99 and 1999-00 cropping seasons. \*There is no significant difference between the same letters statistically at 5 % level

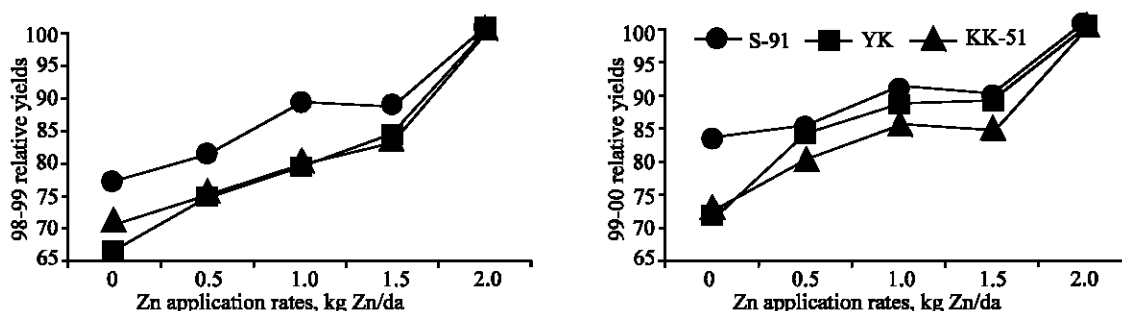


Fig. 2: Effects of Zn application rates on the relative yields of Sazak-91 (S-91), Yerli Kırmızı (YK), Kışlık kırmızı-51 (KK-51) lentil cultivars during the 1998-99 and 1999-00 cropping seasons

and 28.0%, respectively. According to average yields of the cultivars at the different Zn application rates in 1998-99 and 1999-00 seasons, the highest yields were obtained as 60.78 and 71.35 kg da<sup>-1</sup> at the 2.0 kg Zn da<sup>-1</sup> application and the lowest yields were 43.17 and 54.24 kg da<sup>-1</sup> at the control application, respectively.

Effects of Zn application rates on relative yields (RY= [yield at Zn application rates / yield at the highest Zn application rate] × 100) of three cultivars are given in Fig. 2. Regardless of the differences in the cultivars, average relative yield of the cultivars at the control in 1998-99 and 1999-00 seasons were obtained as 71 and 76%, respectively. In both the cropping seasons, Sazak-91 had the highest relative yields. Relative yields of the cultivars at the non-fertilized or Zn deficient condition in 1998-99 and 1999-00 were increased in order YK<71 and 73% in KK-51<77 and 82% in S-91, respectively. In the first cropping season, YK and KK-51 cultivars had the similar relative yields each other at the different Zn application rates, except the control

application. However, in 1999-00 cropping season, relative yields of YK were higher than that of KK-51.

Changes in nutrient concentrations in the grain of three cultivars with different Zn application rates are given in Table 2. Nitrogen (N), phosphorus (P) and potassium (K) concentrations of the cultivars were not significantly influenced by the different Zn application rates, except K concentration of YK in both years and P concentration of S-91 in 1999-00. According to year × cultivars interaction, mean N and P concentrations of the cultivars were significantly affected by the Zn application at p<0.05 and p<0.01 respectively, but mean K concentrations of the cultivars were not. Mean N concentrations of the cultivars increased in order S-91<YK<KK-51 with an average of 3.55% in 1998-99 and KK-51<S-91<YK with an average of 3.80% in 1999-00 cropping season. Mean P concentrations of the cultivars increased in order YK<S-91<KK-51 with an average of 0.25% in 1998-99 and YK≈KK-51<S-91 with an average of 0.18% in 1999-00. Mean K concentrations increased in

Table 2: Effects of different Zn application rates on nutrient concentrations<sup>1</sup> of Sazak-91 (S-91), Yerli Kırmızı (YK), Kışık kırmızı-51 (KK-51) lentil cultivars during the 1998-99 and 1999-00 cropping seasons

| Cultivars          | Zn Rate kg Zn da <sup>-1</sup> | N<br>% | P<br>%  | K<br>%  | Zn<br>mg kg <sup>-1</sup> | Fe<br>mg kg <sup>-1</sup> | Mn<br>mg kg <sup>-1</sup> | Cu<br>mg kg <sup>-1</sup> |
|--------------------|--------------------------------|--------|---------|---------|---------------------------|---------------------------|---------------------------|---------------------------|
| S-91<br>(98-99)    | 0                              | 3.55   | 0.25    | 1.18    | 29B**                     | 106A**                    | 29A*                      | 7.4                       |
|                    | 0.5                            | 3.19   | 0.26    | 1.04    | 31AB                      | 61BC                      | 24AB                      | 7.2                       |
|                    | 1.0                            | 3.09   | 0.25    | 0.88    | 36A                       | 81B                       | 33A                       | 8.2                       |
|                    | 1.5                            | 3.28   | 0.24    | 1.20    | 32AB                      | 54C                       | 23B                       | 7.4                       |
|                    | 2.0                            | 3.64   | 0.27    | 1.45    | 29B                       | 71BC                      | 32A                       | 8.2                       |
|                    | Mean                           | 3.35D  | 0.25AB  | 1.15    | 31C                       | 75C                       | 28                        | 7.7                       |
| YK<br>(98-99)      | 0                              | 3.49   | 0.23    | 1.14AB* | 16B**                     | 89A**                     | 31                        | 8.0                       |
|                    | 0.5                            | 3.38   | 0.24    | 0.81B   | 22B                       | 60B                       | 26                        | 8.0                       |
|                    | 1.0                            | 3.42   | 0.26    | 0.73B   | 25B                       | 107A                      | 31                        | 8.2                       |
|                    | 1.5                            | 3.71   | 0.24    | 1.51A   | 39A                       | 54B                       | 22                        | 7.8                       |
|                    | 2.0                            | 3.64   | 0.25    | 1.30A   | 26B                       | 48B                       | 27                        | 8.2                       |
|                    | Mean                           | 3.47CD | 0.24AB  | 1.10    | 26D                       | 72C                       | 27                        | 8.0                       |
| KK-51<br>(98-99)   | 0                              | 3.66   | 0.26    | 0.77    | 24B**                     | 103A**                    | 30                        | 8.6                       |
|                    | 0.5                            | 3.74   | 0.27    | 0.79    | 30A                       | 92B                       | 33                        | 8.2                       |
|                    | 1.0                            | 3.51   | 0.26    | 1.33    | 33A                       | 62D                       | 29                        | 7.6                       |
|                    | 1.5                            | 3.45   | 0.28    | 1.03    | 27AB                      | 62D                       | 31                        | 8.2                       |
|                    | 2.0                            | 3.73   | 0.25    | 0.87    | 29AB                      | 71C                       | 32                        | 8.4                       |
|                    | Mean                           | 3.62BC | 0.26A** | 0.96    | 29CD                      | 78C                       | 31                        | 8.2                       |
| 98-99              | Gen Mean                       | 3.55   | 0.25    | 1.07    | 29                        | 75                        | 29                        | 8.0                       |
| S-91<br>(99-00)    | 0                              | 3.62   | 0.19B*  | 0.92    | 30B*                      | 157A**                    | 37B**                     | 5.4C*                     |
|                    | 0.5                            | 3.85   | 0.18B   | 0.77    | 32B                       | 141AB                     | 55AB                      | 9.2A                      |
|                    | 1.0                            | 3.86   | 0.22A   | 0.86    | 36B                       | 130B                      | 37B                       | 7.4AB                     |
|                    | 1.5                            | 3.98   | 0.17B   | 0.88    | 48A                       | 76C                       | 43B                       | 7.0BC                     |
|                    | 2.0                            | 3.64   | 0.19B   | 0.83    | 30B                       | 48D                       | 71A                       | 6.6BC                     |
|                    | Mean                           | 3.79AB | 0.19BC  | 0.85    | 34C                       | 110B                      | 49                        | 7.1                       |
| YK<br>(99-00)      | 0                              | 3.98   | 0.17    | 0.76B** | 27D**                     | 170A**                    | 41B**                     | 7.6                       |
|                    | 0.5                            | 3.83   | 0.18    | 0.80AB  | 35CD                      | 179A                      | 43B                       | 5.8                       |
|                    | 1.0                            | 3.63   | 0.18    | 0.77B   | 54A                       | 111B                      | 27B                       | 7.6                       |
|                    | 1.5                            | 4.01   | 0.17    | 0.75B   | 42BC                      | 110B                      | 37B                       | 7.2                       |
|                    | 2.0                            | 3.95   | 0.17    | 0.86AB  | 46AB                      | 81B                       | 70A                       | 7.2                       |
|                    | Mean                           | 3.88A* | 0.17C   | 0.79    | 41B                       | 130A*                     | 44                        | 7.0                       |
| KK-51<br>(99-00)   | 0                              | 3.82   | 0.15    | 0.84    | 31C**                     | 174A**                    | 27B**                     | 8.0                       |
|                    | 0.5                            | 3.54   | 0.16    | 0.74    | 56B                       | 151AB                     | 20B                       | 5.6                       |
|                    | 1.0                            | 3.79   | 0.18    | 0.77    | 69A                       | 63C                       | 60A                       | 6.8                       |
|                    | 1.5                            | 3.52   | 0.17    | 0.85    | 63AB                      | 107BC                     | 62A                       | 6.2                       |
|                    | 2.0                            | 3.92   | 0.19    | 0.83    | 57B                       | 123B                      | 66A                       | 7.0                       |
|                    | Mean                           | 3.72AB | 0.17C   | 0.81    | 55A**                     | 124A                      | 47                        | 6.8                       |
| 99-00              | Gen. Mean                      | 3.80   | 0.18    | 0.81    | 43                        | 121                       | 46                        | 7.0                       |
| Average<br>(98-00) | 0                              | 3.73   | 0.21    | 0.93    | 26B**                     | 133A**                    | 32B**                     | 7.4                       |
|                    | 0.5                            | 3.63   | 0.21    | 0.82    | 34AB                      | 114AB                     | 33B                       | 7.4                       |
|                    | 1.0                            | 3.57   | 0.22    | 0.89    | 42A                       | 92BC                      | 36B                       | 7.6                       |
|                    | 1.5                            | 3.68   | 0.21    | 1.04    | 41A                       | 77C                       | 36B                       | 7.2                       |
|                    | 2.0                            | 3.75   | 0.22    | 1.02    | 36AB                      | 74C                       | 49A                       | 7.6                       |
| 98-00              | Gen. Mean                      | 3.67   | 0.21    | 0.94    | 36                        | 98                        | 38                        | 7.4                       |

<sup>1</sup>The values are the mean of three replicates.

\*There is no significant difference between the same letters in each column statistically at 5 % level.

\*\*There is no significant difference between the same letters in each column statistically at 1 % level.

Table 3: Effects of different Zn application rates on Zn uptake<sup>1</sup> of Sazak-91 (S-91), Yerli Kırmızı (YK), Kışık kırmızı-51 (KK-51) lentil cultivars during the 1998-99 and 1999-00 cropping seasons

| Zn Rate kg Zn da <sup>-1</sup> | mg Zn uptake by grain / plot |         |         |         |           |         |         |         |
|--------------------------------|------------------------------|---------|---------|---------|-----------|---------|---------|---------|
|                                | 1998-1999                    |         |         |         | 1999-2000 |         |         |         |
|                                | S-91                         | YK      | KK-51   | Mean    | S-91      | YK      | KK-51   | Mean    |
| 0                              | 8.32C*                       | 3.07C*  | 3.91B** | 5.10C** | 9.95C*    | 7.23B** | 6.67B** | 7.95C** |
| 0.5                            | 9.48BC                       | 4.80BC  | 5.43AB  | 6.57BC  | 10.86BC   | 10.92AB | 13.86A  | 11.72B  |
| 1.0                            | 11.80A                       | 5.61ABC | 6.29A   | 7.90AB  | 13.01A    | 17.71A  | 17.51A  | 16.07A  |
| 1.5                            | 10.56ABC                     | 9.37A   | 5.40AB  | 8.44AB  | 15.34AB   | 14.07AB | 15.91A  | 15.11AB |
| 2.0                            | 10.68AB                      | 7.58AB  | 6.96A   | 8.41A   | 11.72AB   | 17.10A  | 17.04A  | 15.29A  |
| Mean                           | 10.17A**                     | 6.09B   | 5.60B   |         | 12.17     | 13.14   | 14.10   |         |
| Gen. mean                      |                              |         | 7.28    |         |           |         | 13.23   |         |

<sup>1</sup>The values are the mean of three replicates.

\*There is no significant difference between the same letters at 5 % level.

\*\*There is no significant difference between the same letters at 1 % level.

Table 4: Relationships among the relative yield, Zn concentration and Zn uptake for Sazak-91 (S-91), Yerli kırmızı (YK) and Kışlak kırmızı-51 (KK-51) cultivars

|           | Relative yield |         |         |         |           |         |         |         |
|-----------|----------------|---------|---------|---------|-----------|---------|---------|---------|
|           | 1998-1999      |         |         |         | 1999-2000 |         |         |         |
|           | S-91           | YK      | KK-51   | Mean    | S-91      | YK      | KK-51   | Mean    |
| Zn concn. | 0.031          | 0.479   | 0.203   | 0.385   | 0.028     | 0.474   | 0.431   | 0.441   |
| Zn uptake | 0.561*         | 0.699** | 0.758** | 0.764** | 0.521*    | 0.741** | 0.663** | 0.798** |

\* Correlation is statistically significant at 5% level.

\*\*Correlation is statistically significant at 1% level.

Table 5. Relationships between Zn concentration and other nutrients for Sazak-91 (S-91), Yerli kırmızı (YK) and Kışlak kırmızı-51 (KK-51) cultivars

| Years     | Cultivars | N     | P       | K      | Fe       | Mn      | Cu     |
|-----------|-----------|-------|---------|--------|----------|---------|--------|
| 1998-1999 | S-91      | 0.089 | -0.595* | 0.186  | -0.344   | -0.313  | 0.256  |
|           | YK        | 0.331 | -0.221  | 0.488  | -0.474   | -0.556* | 0.081  |
|           | KK-51     | 0.465 | -0.436  | 0.408  | -0.553*  | -0.622* | -0.095 |
| 1999-2000 | S-91      | 0.474 | -0.387  | 0.096  | -0.599*  | -0.302  | -0.029 |
|           | YK        | 0.247 | -0.184  | 0.101  | -0.724** | -0.141  | 0.070  |
|           | KK-51     | 0.108 | 0.157   | -0.161 | -0.867** | 0.380   | -0.107 |

\* Correlation is statistically significant at 5% level.

\*\*Correlation is statistically significant at 1% level.

order KK-51<YK<S-91 with an average of 1.07% in 1998-99 and YK<KK-51<S-91 with an average of 0.81% in 1999-00.

Zinc (Zn) and iron (Fe) concentrations of the cultivars were significantly influenced by the different Zn application rates. According to year x cultivars interaction, mean Zn and Fe concentrations of the cultivars showed significant increases in the second year, but mean Mn and Cu concentrations did not. Mean Zn concentration of the cultivars increased in order YK < KK-51<S-91 with an average of 29 mg kg<sup>-1</sup> in 1998-99 and S-91<YK<KK-51 with an average of 43 mg kg<sup>-1</sup> in 1999-00. Mean Fe concentration of the cultivars increased in order YK < S-91 < KK-51 with an average of 75 mg kg<sup>-1</sup> in 1998-99 and S-91 < YK < KK-51 with an average of 121 mg kg<sup>-1</sup> in 1999-00. Zn concentrations of the cultivars significantly increased with increasing the Zn application rates over the non-fertilized control, but decreased at the highest application rate of 2.0 kg Zn da<sup>-1</sup>. In contrary, Fe concentration of the cultivars significantly decreased with increasing Zn application rates. Manganese (Mn) concentration of S-91 in 1998-99 and copper (Cu) concentration of S-91 in 1999-00 were significantly influenced by the different Zn application rates. Zn fertilization rates had significant effects on Mn concentrations of all cultivars (p<0.01) in the second year. Mean manganese (Mn) concentration of the cultivars increased in order YK < S-91 < KK-51 with an average of 29 mg kg<sup>-1</sup> in 1998-99 and YK < KK-51 < S-91 with an average of 46 mg kg<sup>-1</sup> in 1999-00. Mean copper (Cu) concentration of the cultivars increased in order S-91 < YK < KK-51 with an average of 8.0 mg kg<sup>-1</sup> in 1998-99 and KK-51 < YK < S-91 with an average of 7.0 mg kg<sup>-1</sup> in 1999-00. Zn fertilization had the significant effects on the general means of all macro and micronutrient concentrations of the cultivars between the years (p<0.01). Comparing the first cropping season with the

second one, general mean of the N, Zn, Fe and Mn concentrations of the cultivars increased, while the mean of P, K and Cu concentrations decreased in 1999-00 cropping season. In order to see the effects of Zn application rates on nutrient concentrations of lentil, average nutrient concentrations of the cultivars in both cropping seasons are also given in Table 2. Average Zn, Fe and Mn concentrations of lentil were significantly influenced by the different Zn application rates.

Zn uptakes by the cultivars from the plots were significantly affected by the Zn application rates in all cropping seasons (Table 3). Zn uptakes by grain increased with increasing Zn application rates over the control. The Zn uptakes by the cultivars in the first year were lower than the Zn uptakes in the second year. Mean Zn uptake of the cultivars increased in order KK-51 < YK < S-91 with an average of 7.28 mg Zn plot<sup>-1</sup> in 1998-99 (p<0.01) and S-91 < YK < KK-51 with an average of 13.23 mg Zn plot<sup>-1</sup> in 1999-00. In both the cropping seasons, Zn application rates from 1.0 to 2.0 kg Zn da<sup>-1</sup> did not have statistically significant effects on the increments in the Zn uptakes by the cultivars.

The relative yields (RY) of the cultivars were significantly correlated with Zn uptake, but not with zinc concentration (Table 4). In the first year, S-91 with high RY had more Zn uptake than the other cultivars with low RY. Increments in the RY by the Zn applications caused to increases in the Zn uptake values in 1999-00. In both the years, correlations between RY and Zn uptake for YK and KK-51 were higher than that for S-91.

## DISCUSSION

**Zn efficiency and Zn uptake:** The grain yield of all cultivars in both cropping seasons significantly increased with increasing the Zn fertilization and the highest yields were obtained at the highest Zn application rate (Fig. 1).

Application of 2.0 kg Zn da<sup>-1</sup> increased the average yield of lentil 40.8% in the first year and 31.6% in the second year over the non-fertilized condition. Although the increase in the average grain yields over the control in the second year were lower than that in the first year, effects of Zn fertilization on the increases in average yields in the second year were 8.9% in S-91, 35.6% in YK and 28.0% in KK-51 over the first year. Average relative yield at non-fertilized application increased from 71% in 1998-99 to 76% in 1999-00. Zn uptakes and relative yields of the cultivars increased with increasing Zn fertilization rates. Increases in the Zn uptake and RY in the second year were higher than that in the first year. Zn efficiency was defined as the ratio of grain yield produced under Zn deficiency compared to Zn fertilization by a numerous studies<sup>[32,33]</sup>. The term Zn efficiency indicates the ability of a genotype to grow and yield better under Zn deficient conditions than other genotypes<sup>[33]</sup>. Çakmak *et al.*<sup>[11]</sup> reported that the combination of high pH, CaCO<sub>3</sub> and low organic matter (<2%), together with low annual precipitation, ranging from 280 to 400 mm were the major factors for Zn deficiency in Central Anatolia. Ekiz *et al.*<sup>[16]</sup> determined that cereal species and their cultivars under rainfed conditions were more sensitive to Zn deficiency than under irrigated conditions. In this study, in addition to low organic matter content, high pH and CaCO<sub>3</sub> contents in the soil (Table 1), lower precipitation in the first year (250 mm) than in the second year (280 mm) most probably caused to decrease plant available Zn content in the soil. In both cropping seasons, Sazak-91 had the highest relative yields and was the most Zn efficient one compared with the other cultivars. Average RY of the cultivars at the control application increased from 71% in the first year to 76% in the second year. Increases in grain yield, Zn uptake and RY of the cultivars in the second year indicated that the cultivars were more sensitive the Zn deficiency under the drought conditions in the first year. YK was the most sensitive to the Zn deficiency under drought conditions because of having the highest increase rate in average grain yield (35.6%) between the years. Sensitivity of the cultivars increased in order Sazak-91 < Kışlık kırmızı-51 < Yerli kırmızı. Kalaycı *et al.*<sup>[33]</sup> reported that wheat cultivars improved for irrigated conditions had high sensitivity to Zn deficiency and had low Zn efficiency under Zn deficient conditions in the field or greenhouse. They found that increases in the grain yield of wheat cultivars by the Zn fertilization varied from 8 to 76% and average Zn efficiency values ranged from 57 to 92% for grain yield.

The correlations between RY and Zn uptake were higher than the correlations between RY and Zn concentration in all cultivars (Table 5). Hart *et al.*<sup>[34]</sup> indicated that the rate of Zn uptake might be an important predictor of Zn efficiency for breeding durum wheat lines

that are more efficient in extracting Zn from soil solution. Kalaycı *et al.*<sup>[33]</sup> reported that there was no relation between Zn efficiency values and Zn concentrations in grain of wheat cultivars, by contrast Zn content was significantly correlated with Zn efficiency. They concluded that Zn concentration in Zn efficient cultivars with high dry matter production were diluted to concentration similar to those in Zn inefficient cultivars. In this study, relationships between the average values of Zn uptake and RY of the cultivars showed that increasing Zn fertilization rate increased the relative yield in different magnitude among the cultivars (Fig. 3). S-91 had the highest Zn uptake and was the most Zn efficient under Zn deficient condition. However, the highest correlation between the average values of Zn uptake and RY ( $r = 0.822^{**}$ ) was obtained for Yerli kırmızı. It indicates that YK was the most sensitive to Zn deficiency and gave the higher response to Zn fertilization. Graham *et al.*<sup>[18]</sup> reported that Zn efficient cereal strains take up more Zn from the environments with low Zn availability and accumulate more dry matter compared to the Zn inefficient ones, but may not always produce seed with higher Zn concentration. In another study, Çakmak *et al.*<sup>[8]</sup> studied on genotypical differences in Zn efficiency among cereal species and found that there were large genotypical differences among wheat lines. In their study, high Zn efficiency was closely associated with enhanced capacity of some lines to take up Zn from soil, but not with increased Zn accumulation per unit dry weight of grain.

**Nutrient composition:** The nutrient values determined for three lentil cultivars (Table 2) were suitable with the average nutritional values, taken from the USDA Agricultural Research Service; 28.1% protein, 0.454% P, 0.905% K, 36 ppm Zn, 90.2 ppm Fe, 14 ppm Mn and 9 ppm Cu<sup>[35]</sup> and also agree with the another study by Erefej and Haddad<sup>[36]</sup>. Rengel *et al.*<sup>[12]</sup> reported that crop species would have differing micronutrient density in grain when grown under similar conditions. In this study, the lentil cultivars had different nutrient concentrations each other under the same grown conditions in both cropping seasons (Table 2). Macro and micro nutrient values of the cultivars were significantly varied between the 1998-99 and 1999-00 cropping seasons. While the mean of the N, Zn, Fe and Mn concentrations of the cultivars increased, the mean of P, K and Cu concentrations decreased in the second cropping season. Quantities of minerals in edible portions of crops are affected by numerous factors, including plant genotype, soil properties, environmental conditions and nutrient interactions<sup>[13]</sup>. It has been known that some environmental factors such as rain, temperature and low moisture content in soil have important effects on the efficiencies of Zn and other plant nutrients in soil<sup>[10]</sup>.

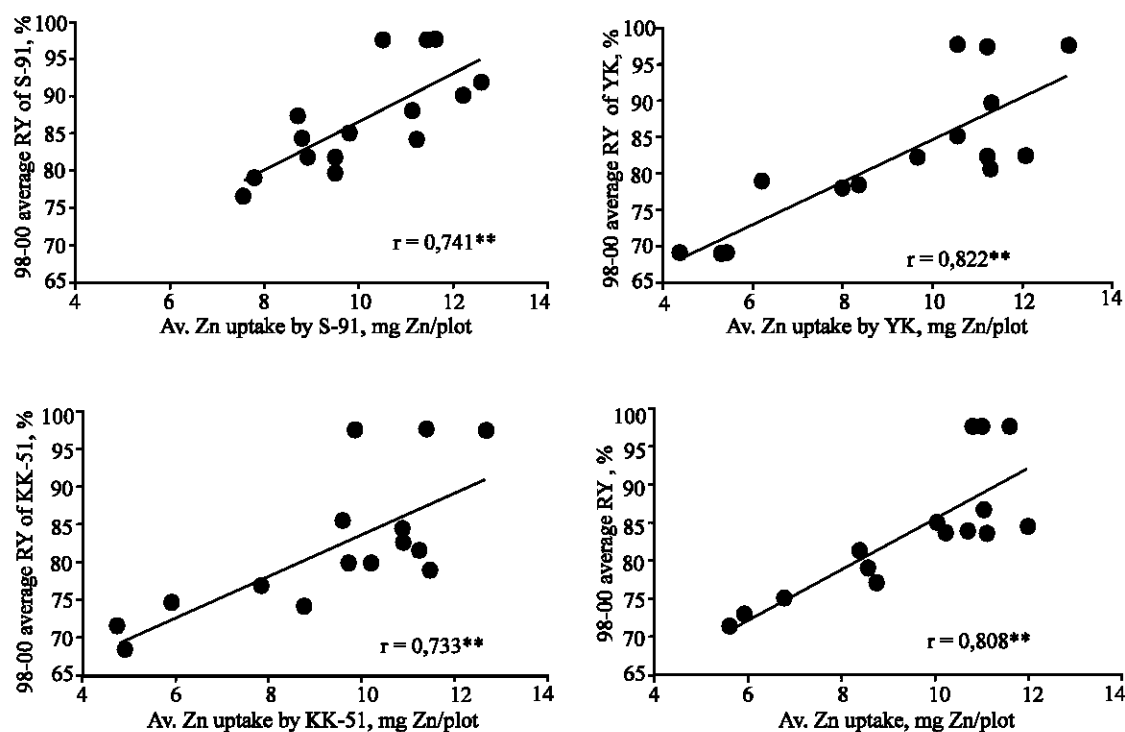


Fig. 3: Relationships between the average relative yield and average Zn uptakes of Sazak-91 (S-91), Yerli Kırmızı (YK), Kışlık kırmızı-51 (KK-51) lentil cultivars

Although Zn application rates were the same for each year, as it was mentioned above, these differences in the nutrient values among the cultivars might be occurred by the differences in precipitation amount between the cropping seasons. Plant available Zn content in soil most probably increased due to increasing soil moisture content in the second year. Thus, average Zn concentrations in grain significantly increased from 29 mg Zn kg<sup>-1</sup> in the first year to 55 mg Zn kg<sup>-1</sup> in the second year (Table 2). While the highest average Zn concentration value (42 mg Zn kg<sup>-1</sup>) was obtained at the 1.0 kg Zn da<sup>-1</sup> application rate, Zn concentration in grain usually decreased at the highest application rate of 2.0 kg Zn da<sup>-1</sup> (Table 2). This decrease in Zn concentration might be explained with dilution effect. Increase in dry matter or grain yield with increasing Zn fertilization diluted Zn concentration in grain. Applications of micronutrient fertilizers to soil at rates below toxicity threshold do not result in linear increases in grain micronutrient concentration<sup>[12]</sup>. In the study by Raboy and Dickinson<sup>[37]</sup>, when Zn fertilization was increased a thousand-fold, seed Zn concentration in *Glycine max* increased to a limited extent only (from 56 to 67 mg Zn kg<sup>-1</sup>). After a certain limit in micronutrient fertilization is exceeded, further increases in fertilization rate cause a decrease in micronutrient density in grain [38]. In this study, average Zn

concentrations in grain for the cultivars increased in order YK < KK-51 < S-91 in 1998-99 and S-91 < YK < KK-51 in 1999-00. Although S-91 showed the highest Zn efficiency in both cropping seasons, Zn concentration of S-91 were not higher than that of the other cultivars in the second year. Kalaycı *et al.*<sup>[33]</sup> found that Zn concentration of Zn efficient wheat cultivars with high dry matter production were diluted to concentration similar to those in Zn inefficient cultivars.

The relationships between Zn concentration and the other nutrients are given in Table 5. In both the cropping seasons, generally Zn concentration of the cultivars were positively correlated with N and K and negatively correlated with P, Fe and Mn concentrations. Cu concentration showed variability with the Zn application. In the study by Paivöke<sup>[39]</sup>, application of 9.3 mmol Zn kg<sup>-1</sup> dry soil increased N and K, decreased P concentrations in cotyledons of *Pisum sativum* compared to the control. Zn and Cu applications to soil significantly increased protein concentration of wheat grain over the control<sup>[40]</sup>. Zn concentration gave the significant negative correlations with P in S-91, Fe in KK-51 and Mn in YK and KK-51 in the first year. Significant Zn x Fe interaction was obtained for all cultivars in the second cropping season in which Zn fertilization was more effective than the first year. The highest Zn and the lowest Fe concentrations for



the cultivars were usually obtained at the 1.0 and 1.5 kg Zn da<sup>-1</sup> application rates. Effects of Zn fertilization rates on Mn concentration were similar to the Fe concentration. Mn concentration gave the negative correlations with the Zn concentration of the cultivars, except Mn concentration of KK-51 in the second year. It has been reported that the most common effect of Zn deficiency other than its effect on P uptake is to increase shoot levels of Mg and Mn concentration<sup>[41,42]</sup>. A numerous studies indicated that Zn deficiency in plants might cause high concentrations of P that are potentially toxic<sup>[43,44]</sup>. In this study increasing Zn availability in the second year caused decreases in the P concentration in grain of all cultivars over the first year. Parker<sup>[14]</sup> determined that Zn concentrations of six crop species were increased with increasing Zn application rates, but P concentrations decreased. He reported that the effects of Zn deficiency on shoot concentrations of nutrients other than P were variable and shoot concentration of Cu, Fe and Mn were often increased in Zn deficient plants at the control application.

Application of different Zn rates into the soil caused significant effects on Zn uptakes and grain yields of three lentil cultivars. Zn efficiency of the cultivars increased with increasing Zn fertilization rates in order Kışlık Kırmızı-51 < Yerli Kırmızı < Sazak 91 (Fig. 2). Regardless of the differences in the cultivars, average relative yield at the control application increased from 71% in 1998-99 to 76% in 1999-00. Drought conditions in the first year caused decreases in Zn uptake, Zn efficiency and grain yield in the first year compared to the second year. Yerli kırmızı was the most sensitive cultivars to Zn deficiency and drought conditions and sensitivity of the cultivars increased in order Sazak 91 < Kışlık Kırmızı-51 < Yerli Kırmızı. Rengel *et al.*<sup>[12]</sup> reported that concentration is a more important measure of micronutrient supply in grain destined for human food than micronutrient content. In both the cropping seasons, Zn uptake and Zn concentration of the cultivars were generally increased with 1.0 and 1.5 kg Zn da<sup>-1</sup> application rates. At the highest Zn application rate, high dry matter production diluted the Zn concentration in grain. While N and K concentration of the cultivars tended to increase with increasing Zn application rates, P, Fe and Mn concentrations tended to decrease. Cu concentration in grain was more variable compared to the other nutrients.

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