# Genotypic response of chickpea (*Cicer arietinum* L.) cultivars to drought stress implemented at pre- and post-anthesis stages and its relations with nutrient uptake and efficiency

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## ABSTRACT

Uptake of mineral nutrients in chickpea cultivars might be an important response in drought tolerance. An experiment under controlled conditions was carried out to study the genotypic response of 11 chickpea (*Cicer arietinum* L.) cultivars to drought and its relations with N, P, K, Ca, Mg, Fe, Zn, Mn and B uptake and uptake efficiency. Plants were grown either optimal or drought stress implemented at pre- (early drought stress, EDS) and post-anthesis (late drought stress, LDS) stages. Growth reduction of the cultivars as a response to drought significantly differed. The results of the study indicated that EDS had less detrimental effects on growth and nutrient uptake than LDS conditions. In general, drought tolerant chickpea cultivars accumulated more N, P, K, Ca, Zn, Mn and B in both drought stress treatments except for Zn and Mn uptake in LDS treatment. The total nutrient uptake efficiency of the cultivars were also very significantly correlated with the growth reduction ration (GR) both in EDS and LDS treatments giving correlation coefficients ($r$) of –7859 and –0.7678, $P < 0.01$, respectively.

**Keywords:** chickpea; drought; stress; tolerance; nutrient uptake efficiency

Chickpea (*Cicer arietinum* L.) is an ancient legume crop believed to have originated in southeastern Turkey and the adjoining part of Syria. It is the second most important pulse crop in the world. It covers 15% of the cultivated area and contributes to 14% (7.9 million ton) of the world's pulse harvest of about 58 million tons (Singh 1997). Besides being an important source of human and animal food, chickpea also plays an important role in the maintenance of soil fertility, particularly in the dry, rainfed areas (Saxena 1990, Katerji et al. 2001). In Turkey, chickpea rotates with cereals or it is grown on land less preferred for cultivation of cereals in rainfed areas. Since it is grown mostly as a rainfed and post-rainy season crop, water stress during vegetative and/or reproductive growth stages is one of the most limiting factors for the chickpea growth. Availability and interaction between soil moisture and nutrients and genotypic variability in nutrient use or uptake of chickpea cultivars are important conditions in chickpea management.

Drought stress may involve the uptake of mineral elements in plant tissues by affecting root growth and nutrient mobility in soil and nutrient uptake (Fageria et al. 2002, Samarah et al. 2004). Decreasing water availability under drought generally results in reduced total nutrient uptake and frequently causes reduced concentrations of mineral nutrients in crop plants. The most important effect of water deficits is observed on the transport of nutrients to the root and on the root growth and extension. Reduced absorption of the nutrient elements results from an interference of nutrient uptake and unloading mechanisms and reduced transpiration flow (Marschner 1995, Baligar et al. 2001). However, plant species and genotypes within species differ in their response to nutrient element uptake under water stress (Garg 2003). Information is lacking on the response of chickpea genotypes to mineral nutrition under drought. In a study carried out by Ali et al. (2002) genotypic differences in response to application of Fe, B and

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Zn were found among chickpea genotypes. Mineral nutrient deficiencies commonly observed in major chickpea producing areas are: nitrogen (due to sub-optimal N fixation), P, S, Fe, Zn and B (Ali et al. 2002). Nutrient uptake in plants under drought stress may have an important role in drought tolerance (Samarah et al. 2004). Drought significantly reduced nutrient use efficiency in plants and selection of improved genotypes adaptable to drought conditions has been a major contribution to the overall gain in crop productivity (Baligar et al. 2001). In many studies, nutrient use efficiency was calculated with the yield obtained from low and optimal nutrient supply without considering abiotic stress situations such as drought. The purpose of the work was to characterize the effect of drought stress in pre- and post anthesis stages on the patterns of nutrient uptake and uptake efficiency, and to examine whether there were major differences between chickpea cultivars.

## MATERIAL AND METHODS

### Cultivar and growth conditions

A total of 11 chickpea (*Cicer arietinum* L.) cultivars (Menemen-92, Akcin, Aydin-92, Izmir-92, Kusmen, Canitez-87, Gokce, Sari, Uzunlu-99, Er-99 and ILC-195) have been used in the experiment. These cultivars have been developed for Turkey, and most of them are grown by farmers. The chickpea cultivars were grown in a glasshouse during the summer of 2004 at the Department of Plant Nutrition and Soil Science, University of Ankara, Turkey. The experiment was carried out in PVC pots holding 3500 g of air-dried soil. Some characteristics of the soil were as follows: field capacity 24%, texture clay loam, $CaCO_3$ 5.48%, pH (1:2.5 water) 7.70, EC 0.23 dS/m, organic matter (OM) 0.76%, total N 0.12%. The concentrations of $NH_4OAc$-extractable K, Ca and Na were as follows (mg/kg): 389, 4800 and 60 mg/kg, respectively. The $NaHCO_3$-available P was 14.50 mg/kg; DTPA-extractable Zn, Fe, Cu and Mn were as follows (mg/kg): 0.57, 5.24, 0.48 and 33, respectively; NaOAc-extractable B was 1.80.

Fifteen seeds were sown in each pot and thinned to twelve after emergence. The cultivars were grown in a glasshouse under natural light conditions (approximate day conditions during the span of the experiment were: 28–32°C air temperature, 550–600 $\mu mol/m^2/s$ light intensity and 45–50% relative humidity). A basal dose of N ($NH_4NO_3$), P and K ($KH_2PO_4$) were applied to all the pots at 50, 50 and 62.5 mg/kg levels, respectively, and mixed thoroughly with soil.

The water content of the soil was maintained at 60% of field capacity in non-stress (control) treatment. All plants were grown for two weeks at 60% of field capacity after emergence. Afterwards, early drought stress (EDS) at pre-anthesis stage was maintained for three weeks by decreasing the moisture level to 40% of the field capacity, than the pots were irrigated again at 60% of field capacity. At the post-anthesis stage, late drought stress (LDS) treatment at another group of pots was initiated at the end of the early drought stress. During the two weeks after the LDS termination, all plants were grown at 60% of field capacity. The pots were moved and rearranged daily to give a random distribution of growth conditions in the glasshouse during the experimental period.

### Harvest and plant analysis

Plants were harvested at the end of the experiment, washed and dried in a thermoventilated oven at 65°C until reaching a constant mass and the dry weights were recorded. Growth reduction (GR) was calculated as the ratio of stressed to unstressed plants (control). For the measurements of mineral nutrients plant samples were ashed in a muffle furnace at 500°C for 6 h and the ash dissolved in 5 ml of 2M $HNO_3$.

Nitrogen was determined by Kjeldahl procedure. Potassium was measured by flamephotometer (Jenway PFP7, ELE Instrument Co. Ltd). Boron was determined spectrophotometrically by the Azomethine-H method (Wolf 1974). Phosphorus was also determined spectrophotometrically (Schimadzu UV-VIS 1201), and Ca, Mg, Fe, Zn, Cu and Mn were determined by AAS (Analytic Jena Vario 6). Nutrient uptake was calculated by multiplying dry weight and individual nutrient concentrations. Nutrient uptake efficiency was calculated as nutrient uptake in EDS or LDS/nutrient uptake in control. Total nutrient uptake efficiency was calculated as the sum of the individual nutrient uptake in EDS or LDS/sum of the individual nutrient uptake in control.

### Trial design and statistical analysis

The experimental design was a three-factorial completely randomized design comprising non-stress (control), early drought stress (EDS) at pre-anthesis and late drought stress (LDS) at post-anthesis stage treatments with four replications. The experimental data were analyzed by ANOVA and the differences were compared by Least Significant Difference Test (LSD) at alpha 0.05. Correlation coefficients (*r*) were also calculated among the parameters.

## RESULTS

### Growth reduction (GR)

Drought stress in both pre- and post-anthesis stages reduced the dry weights of all the cultivars and the responses of the cultivars to early and late drought stress varied. Growth reduction (GR) of all the cultivars was decreased by drought stress as compared to control. At the post-anthesis stage GR of the cultivars was higher, being an average of 47% than the average of 29% at the pre-anthesis stage under drought stress (Figure 1). The results indicated the presence of a considerable amount of genotypic variation among the cultivars under both drought stress conditions.

Kusmen, Canitez-87, Izmir-92, Sari, Gokce and ILC-195 chickpea cultivars were found drought susceptible compared to Akcin, Aydin-92, Er-99, Uzunlu-99 and Menemen-92, because their yield reduction was 29% higher than the average yield reduction value in early drought stress (EDS) treatment. There was also a significant variation between chickpea cultivars under drought stress in the post-anthesis stage. Growth reduction as a result of LDS treatment in Menemen-92, Canitez-87, Kusmen, Gokce, Sari, Er-99 and Izmir-92 cultivars were higher than in the case of cultivars ILC-195, Aydin-92, Akcin, and Uzunlu-99. So, the latter cultivars could be accepted as drought resistant cultivars in LDS. Canitez-87, Izmir-92, Sari and Gokce cultivars were found drought susceptible, whereas Aydin-92, Akcin and Uzunlu-99 were found drought resistant in both pre- and post-anthesis stress conditions. Surprisingly, Menemen-92 was found the most drought resistant of all cultivars in pre-anthesis stage but the least drought resistant in post-anthesis stage.

### Nitrogen (N), phosphorus (P) and potassium (K) uptake and efficiency

Drought stress implemented at pre- and post-anthesis stage significantly decreased N, P and K uptake in plants (Table 1). The reduction in N, P and K uptake was more significant in LDS stage than in EDS stage. The cultivars considerably differed with respect to N, P and K uptake at control and both stress conditions. Calculated N uptake efficiency of drought resistant cultivars Menemen-92, Uzunlu-99, Er-99, Aydin-92 and Akcin varied between 79–91%, compared to 64–73% for EDS treatment differences between drought susceptible cultivars. Nitrogen uptake efficiency of drought resistant cvs. Uzunlu-99, Akcin, Aydin-92 and ILC-195 were also comparatively higher than the susceptible cultivars in LDS stage. There were

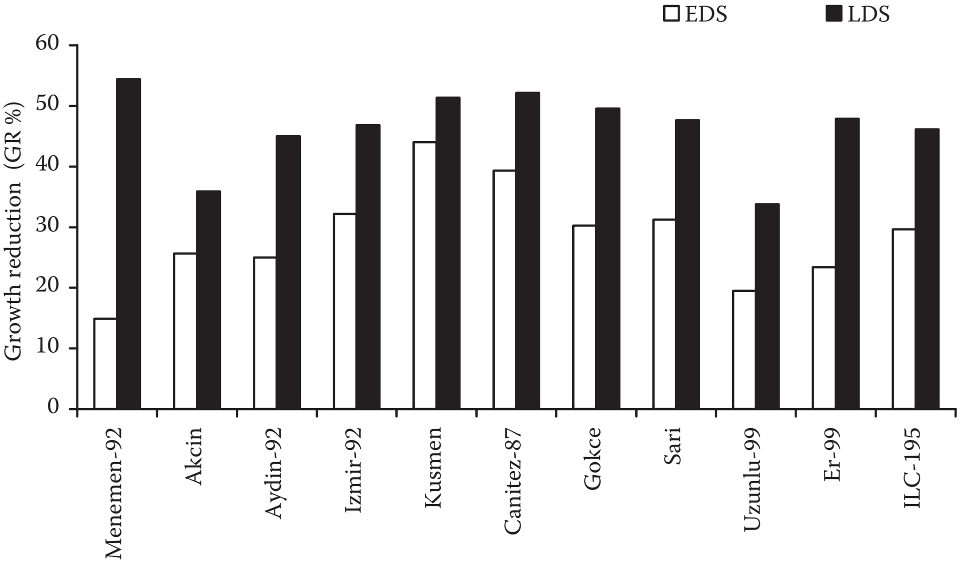

Figure 1. Growth reduction (GR) of chickpea cultivars at early (EDS) and late drought stress (LDS)

Table 1. The effect of early (EDS) and late drought stress (LDS) on the nitrogen (N), phosphorus (P), and potassium (K) uptake of chickpea cultivars; values in parenthesis show a nutrient uptake efficiency calculated as [(nutrient uptake in EDS or LDS/nutrient uptake in control treatments) × 100]

| Cultivars | N (mg/plant) | | | P (mg/plant) | | | K (mg/plant) | | |
|---|---|---|---|---|---|---|---|---|---|
| | control | EDS | LDS | control | EDS | LDS | control | EDS | LDS |
| Menemen-92 | 20.0 | 18.2 (91) | 15.5 (78) | 1.75 | 1.44 (82) | 1.10 (63) | 29.5 | 28.6 (97) | 17.5 (60) |
| Akcin | 20.7 | 16.9 (82) | 18.5 (90) | 2.24 | 1.39 (62) | 1.30 (58) | 34.8 | 28.2 (91) | 22.9 (66) |
| Aydin-92 | 19.0 | 15.0 (79) | 14.9 (78) | 1.47 | 1.25 (85) | 1.09 (74) | 28.3 | 21.2 (75) | 16.4 (58) |
| Izmir-92 | 27.4 | 19.3 (71) | 20.9 (76) | 2.43 | 1.36 (56) | 1.21 (50) | 38.3 | 26.5 (69) | 19.2 (50) |
| Kusmen | 24.6 | 16.8 (68) | 15.3 (62) | 1.63 | 1.18 (72) | 1.04 (64) | 25.2 | 15.7 (62) | 12.3 (49) |
| Canitez-87 | 25.5 | 16.2 (64) | 15.8 (62) | 2.46 | 1.22 (50) | 1.22 (50) | 35.5 | 22.0 (62) | 16.5 (46) |
| Gokce | 26.0 | 17.7 (68) | 15.6 (60) | 2.34 | 1.61 (69) | 1.11 (47) | 29.7 | 21.9 (74) | 15.3 (52) |
| Sari | 30.5 | 23.0 (76) | 21.4 (70) | 2.26 | 1.52 (67) | 1.42 (63) | 32.3 | 22.5 (70) | 17.4 (54) |
| Uzunlu-99 | 15.0 | 13.7 (91) | 13.2 (88) | 1.32 | 1.12 (85) | 1.15 (87) | 19.9 | 16.8 (84) | 13.4 (67) |
| Er-99 | 18.6 | 15.7 (84) | 14.0 (75) | 1.47 | 1.05 (71) | 0.89 (61) | 22.5 | 18.2 (81) | 12.9 (57) |
| ILC-195 | 17.7 | 13.0 (73) | 11.6 (66) | 1.34 | 0.92 (76) | 0.78 (58) | 20.9 | 15.9 (76) | 12.1 (58) |
| LSD for cultivar × drought | | 3.97 | | | 0.383 | | | 4.16 | |
| *F*-value for cultivar × drought | | 1.68* | | | 2.43** | | | 2.58** | |

$^*P < 0.05$, $^{**}P < 0.01$

highly significant negative correlations between GR and N uptake efficiency both in early and late drought stress ($r = –0.9070$ and $r = –0.7610$, $P < 0.01$, respectively).

Phosphorus uptake in the drought resistant cultivars of Menemen-92, Aydin-92, and Uzunlu-99 decreased less as the result of drought stress in pre-anthesis stage, compared to the other drought resistant cultivars (Er-99 and Akcin) and drought susceptible cultivars. In LDS stage, P uptake efficiency of drought resistant cvs. Uzunlu-99 and Aydin-92 was higher than the uptake of other cultivars. There were significant negative correlations between GR and P uptake efficiency both in early and late drought stress ($r = –0.5999$ and $r = –0.5490$, $P < 0.1$, respectively).

In EDS stage, K uptake efficiency of drought resistant cvs. Menemen-92, Uzunlu-99, Er-99, and Akcin varied between 81–97% (with the exception of drought tolerant cv. Aydin-92) and were significantly higher than the uptake of the drought susceptible cultivars. Drought resistant cvs. Uzunlu-99, Akcin, Aydin-92 and ILC-195 also exhibited higher K uptake efficiency, when compared to the drought susceptible cultivars in LDS treatment (Table 2). There was also a highly significant negative correlation between GR and K uptake efficiency both in early and late drought stress ($r = –0.8937$ and $r = –0.7638$, $P < 0.01$, respectively).

## Calcium (Ca) and magnesium (Mg) uptake and efficiency

Ca and Mg uptake and efficiency of chickpea cultivars grown under optimal and drought stress conditions were presented in Table 2. Drought treatments caused decreases in Ca and Mg uptake in all the cultivars. Ca and Mg uptake and efficiency rates greatly differed among the cultivars in optimal and both early and late water stress conditions. The correlation relationships between GR and Ca ($r = –0.584$, $P < 0.1$) uptake at EDS and Mg uptake efficiency ($r = –0.583$, $P < 0.1$ and $r = –0.843$, $P < 0.01$) were found significant at EDS and LDS treatment. In fact, Ca and Mg uptake efficiency of drought resistant cvs. Menemen-92 and Akcin was higher than that of the other drought resistant and susceptible cultivars in EDS stage. Magnesium uptake efficiency of drought resistant cv. Akcin, Uzunlu-99, Aydin-92 was found considerably higher than that of the other cultivars in LDS treatment (Table 2).

Table 2. The effect of early (EDS) and late drought stress (LDS) on the calcium (Ca), and magnesium (Mg) uptake of chickpea cultivars; values in parenthesis show a nutrient uptake efficiency calculated as [(nutrient uptake in EDS or LDS/nutrient uptake in control treatments) × 100]

| Cultivars | Ca (mg/plant) | | | Mg (mg/plant) | | |
|---|---|---|---|---|---|---|
| | control | EDS | LDS | control | EDS | LDS |
| Menemen-92 | 18.6 | 16.1 (87) | 8.9 (48) | 3.47 | 3.01 (87) | 1.98 (57) |
| Akcin | 18.6 | 15.7 (85) | 13.2 (71) | 3.82 | 3.34 (87) | 3.06 (80) |
| Aydin-92 | 18.4 | 13.5 (73) | 9.8 (53) | 3.36 | 2.47 (73) | 2.22 (66) |
| Izmir-92 | 26.0 | 21.8 (84) | 19.1 (73) | 4.81 | 3.13 (65) | 2.91 (60) |
| Kusmen | 31.5 | 17.9 (57) | 15.9 (51) | 4.40 | 2.75 (63) | 2.53 (57) |
| Canitez-87 | 28.2 | 19.0 (67) | 15.0 (53) | 4.40 | 2.78 (63) | 2.66 (60) |
| Gokce | 30.5 | 19.8 (65) | 16.8 (55) | 4.65 | 2.97 (64) | 2.67 (57) |
| Sari | 29.0 | 22.5 (77) | 19.1 (66) | 4.39 | 3.30 (75) | 3.09 (70) |
| Uzunlu-99 | 16.0 | 11.1 (69) | 9.0 (56) | 2.76 | 1.84 (67) | 1.98 (72) |
| Er-99 | 18.9 | 14.1 (75) | 10.5 (56) | 3.32 | 2.41 (72) | 2.09 (63) |
| ILC-195 | 10.9 | 8.7 (80) | 6.2 (58) | 2.43 | 1.96 (81) | 1.45 (60) |
| LSD for cultivar × drought | | 4.06 | | | 0.680 | |
| *F*-value for cultivar × drought | | 2.22** | | | 1.62** | |

*$P < 0.05$, **$P < 0.01$

Table 3. The effect of early (EDS) and late drought stress (LDS) on the iron (Fe), and zinc (Zn) uptake of chickpea cultivars; values in parenthesis show a nutrient uptake efficiency calculated as [(nutrient uptake in EDS or LDS/nutrient uptake in control treatments) × 100]

| Cultivars | Fe (μg/plant) | | | Zn (μg/plant) | | |
|---|---|---|---|---|---|---|
| | control | EDS | LDS | control | EDS | LDS |
| Menemen-92 | 54.1 | 53.0 (98) | 44.2 (82) | 15.3 | 13.9 (91) | 9.2 (60) |
| Akcin | 72.5 | 46.3 (64) | 39.2 (54) | 23.0 | 16.1 (70) | 13.8 (60) |
| Aydin-92 | 42.1 | 36.0 (85) | 28.7 (68) | 18.3 | 14.1 (77) | 10.8 (59) |
| Izmir-92 | 79.6 | 59.1 (74) | 41.9 (53) | 26.4 | 14.7 (56) | 11.4 (43) |
| Kusmen | 49.0 | 51.0 (104) | 27.5 (56) | 15.7 | 11.2 (71) | 9.2 (58) |
| Canitez-87 | 78.9 | 43.7 (55) | 37.0 (47) | 22.7 | 13.9 (61) | 11.7 (51) |
| Gokce | 94.3 | 66.4 (70) | 45.9 (49) | 28.1 | 16.7 (59) | 13.8 (49) |
| Sari | 62.1 | 55.2 (89) | 49.1 (79) | 26.1 | 17.6 (67) | 15.6 (60) |
| Uzunlu-99 | 36.3 | 23.7 (65) | 33.4 (92) | 15.8 | 10.0 (63) | 9.7 (61) |
| Er-99 | 41.3 | 31.4 (76) | 27.8 (67) | 14.8 | 11.9 (80) | 9.5 (64) |
| ILC-195 | 42.4 | 36.3 (86) | 25.9 (61) | 15.7 | 10.5 (67) | 8.2 (52) |
| LSD for cultivar × drought | | 15.64 | | | 3.59 | |
| *F*-value for cultivar × drought | | 2.41** | | | 2.36** | |

**$P < 0.01$

### Iron (Fe) and zinc (Zn) uptake and efficiency

Fe and Zn uptake and efficiency also varied among the cultivars; their uptake decreased markedly, with the exception of cv. Kusmen for Fe, under water stress at both growing stages as compared to optimal conditions. Except Uzunlu-99, uptake efficiency of Fe and Zn decreased severely in LDS treatment. A negative relationship ($r = -0.529$, $P < 0.1$) between GR and Zn uptake efficiency was observed in EDS stage, while Fe and Zn uptake efficiency was not correlated significantly in other cases (Table 3). In addition, only the Menemen cultivar, which was found drought tolerant, exhibited a good performance for Fe and Zn uptake efficiency in EDS stage.

### Manganese (Mn) and boron (B) uptake and efficiency

Table 4 shows considerable differences in Mn and B uptake efficiency between chickpea cultivars. Mn and B uptake of the cultivars decreased under water stress. The decreases in Mn and B uptake were more serious in LDS treatment. In EDS stage, Mn uptake decreased less as a result of drought in drought resistant cultivars of Menemen, Akcin and Er-99 and their Mn uptake efficiency were calculated as 84%, 76% and 73%, respectively (Table 4). There was a significant negative relationship between GR and Mn uptake efficiency ($r = -0.520$, $P < 0.1$) in EDS, while it was found not significant in LDS (Table 4).

Growth reduction (GR) of the cultivars and B uptake efficiency is negatively correlated both in EDS and LDS conditions ($r = -0.7489$ and $r = -6984$, $P < 0.01$, respectively). Boron uptake efficiency of drought tolerant cvs. Menemen-92, Aydin-92, Er-99 and Akcin were found significantly higher than that of drought susceptible cultivars in EDS (Table 4). In LDS condition, B uptake efficiency of drought tolerant cvs. Akcin and Uzunlu-99 exhibited a good performance and the decrease in B uptake as a result of drought stress was significantly lower than in the case of other cultivars.

### Yield reduction and total nutrient uptake efficiency

The average values of the total (N, P, K, Ca, Mg, Fe, Zn, Mn and B) nutrient uptake efficiency of

Table 4. The effect of early (EDS) and late drought stress (LDS) on the manganese (Mn), and boron (B) uptake of chickpea cultivars; values in parenthesis show a nutrient uptake efficiency calculated as [(nutrient uptake in EDS or LDS/nutrient uptake in control treatments) × 100]

| Cultivars | Mn (μg/plant) | | | B (μg/plant) | | |
|---|---|---|---|---|---|---|
| | Control | EDS | LDS | Control | EDS | LDS |
| Menemen-92 | 37.2 | 31.2 (84) | 19.2 (52) | 49.5 | 44.0 (89) | 24.0 (48) |
| Akcin | 45.0 | 34.1(76) | 25.7 (57) | 57.0 | 44.0 (77) | 36.5 (64) |
| Aydin-92 | 37.6 | 23.3 (62) | 19.1 (51) | 50.0 | 37.5 (76) | 27.0 (54) |
| Izmir-92 | 55.3 | 34.7 (63) | 25.8 (47) | 62.4 | 41.8 (67) | 33.9 (54) |
| Kusmen | 37.4 | 22.6 (61) | 21.8 (58) | 47.6 | 31.3 (66) | 26.5 (56) |
| Canitez-87 | 53.7 | 34.9 (65) | 28.2 (52) | 52.8 | 35.3 (67) | 26.8 (51) |
| Gokce | 37.0 | 27.5 (74) | 23.3 (63) | 57.3 | 37.5 (65) | 32.9 (57) |
| Sari | 50.3 | 36.7 (73) | 32.4 (64) | 58.3 | 43.3 (74) | 35.5 (61) |
| Uzunlu-99 | 25.5 | 16.2 (64) | 15.6 (61) | 32.2 | 23.1 (72) | 20.8 (65) |
| Er-99 | 33.2 | 24.4 (73) | 19.8 (60) | 37.9 | 32.1 (85) | 24.9 (66) |
| ILC-195 | 41.5 | 23.4 (56) | 20.7 (50) | 35.8 | 27.8 (77) | 20.7 (58) |
| LSD for cultivar × drought | | 6.79 | | | 7.88 | |
| *F*-value for cultivar × drought | | 1.85* | | | 1.69* | |

*$P < 0.05$

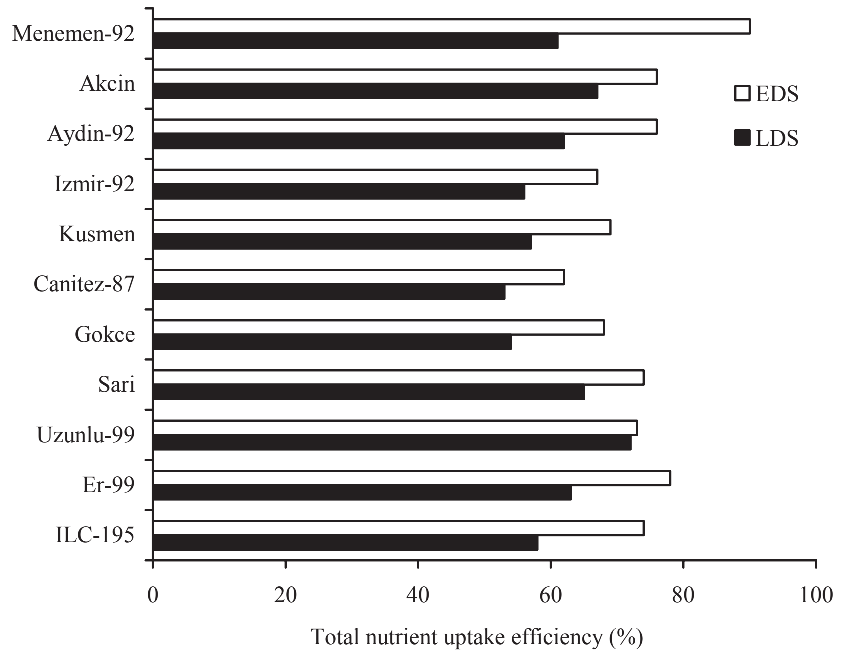

Figure 2. Effect of early (EDS) and late drought stress (LDS) on total nutrient (N, P, K, Ca, Mg, Fe, Zn, Mn and B) uptake efficiency of chickpea cultivars

the 11 chickpea cultivars in EDS and LDS conditions are presented in Figure 2. Drought resistant cultivars both in EDS and LDS conditions generally showed a higher uptake of mineral nutrients under the drought conditions. Very close negative relationships between GR (Figure 1) and total nutrient uptake efficiency in both stress conditions ($r = -0.7859$, $P < 0.01$ and $r = -0.7678$, $P < 0.05$, respectively) were established. In general, total nutrient uptake efficiency of the drought tolerant cultivars (Menemen-92, Akcin, Aydin-92, Uzunlu-99 and Er-99) in EDS was significantly higher, compared to the drought susceptible cultivars. Drought tolerant cvs. Aydin-92, Akcin and Uzunlu-99 were also higher in nutrient uptake efficiency in comparison to the other cultivars in LDS treatment (Figure 2).

## DISCUSSION

Drought is deleterious for plant growth, yield and mineral nutrition (Garg et al. 2004, Samarah et al. 2004) and drought stress is one of the worst scourges of agriculture (Reddy et al. 2004). Cultivars differ in their response to environmental stress at different growth stages. Better understanding of genotypic control of nutrient uptake mechanisms is required for chickpea to maintain the production under rainfed or drought conditions. The present study showed a substantial genotypic variation in drought tolerance in early and late growing stages between 11 chickpea cultivars (Figure 1). Bruckner and Frohberg (1987) suggest that cultivars with low growth reduction values are presumed to be drought resistant because they exhibit a smaller reduction in dry weight than the average dry weight under stress compared with favorable conditions. Similarly, cultivars exhibiting smaller reduction in nutrient uptake and efficiency should be presumed to be drought resistant, and nutrient uptake efficiency involves drought tolerance mechanisms. In our study, screened chickpea cultivars were divided into two groups as drought sensitive and tolerant according to GR values determined under the drought treatments implemented at pre- and post-anthesis stage of the growth. In this respect, Akcin, Aydin-92, Er-99, Uzunlu-99 and Menemen-92 cultivars exhibited comparatively lower GR than the average of all the cultivars in early drought stress conditions. In the case of late drought stress treatment, at post-anthesis stage, cvs. ILC-195, Aydin-92, Akcin, and Uzunlu-99 were found drought tolerant. Besides, Aydin-92, Akcin and Uzunlu-99 cultivars were found drought resistant in both drought stress conditions. In the study carried out by Anbessa and Bejiga (2002) drought tolerance of 482 genotypes of chickpea collected from different regions of Ethiopia was investigated. There were great differences between the genotypes and 18 genotypes were identified as drought tolerant based on the drought response. Boutraa and Sanders (2001) previously reported that the reduction in yield and growth parameters differed in two bean cultivars imposed to water stress during flowering and pod filling stages. Evidence presented in this study indicates that drought had less detrimental effects in early than in late drought stress conditions. This result is in accordance with the findings of Xia (1997) who reported that yield reduction in faba bean was higher in drought stress from full pod-set to maturity than the drought from initiation of pod-set to full pod set.

Decreasing water availability under drought generally results in reduced total nutrient uptake and frequently reduces the concentrations of mineral nutrients in crop plants (Marschner 1995, Baligar et al. 2001). Plant species and genotypes within species vary in their response to mineral uptake under water stress (Garg 2003). In the present study 11 screened chickpea cultivars greatly varied with respect to nutrient uptake in optimal and both drought stress conditions. Great differences were reported previously in N, P and K uptake among 20 genotypes of chickpea (Gallani et al. 2003). Drought treatments significantly reduced nutrient uptake and efficiency of the cultivars and the decrease in nutrient uptake was more serious in LDS treatment than that of the EDS treatment. According to Rengel (2001), on soils under micronutrient deficiency, micronutrient-efficient genotypes have a greater yield in comparison to inefficient ones. In a study carried out with faba bean under water deficit, N, P and K uptake significantly decreased (Xia 1997). In general, drought tolerant chickpea cultivars in both drought stress treatments accumulated more N, P, K, Ca, and B in their tissue. Zn and Mn uptake in the drought tolerant cultivars in EDS treatment was also higher than in the case of the sensitive genotypes. When the total nutrient uptake efficiency of the cultivars are considered, significant correlations are observed between GR and nutrient uptake efficiency both in EDS and LDS treatment giving correlation coefficients ($r$) of –7859 and –0.7678, $P < 0.01$, respectively. In the present study, cultivars accepted as drought tolerant on the basis of their GR generally showed higher individual or total nutrient uptake efficiency rates. As suggested by Samarah et al. (2004) this also indicates that nutrient efficiency may involve drought tolerance mechanisms and selection of nutrient-efficient cultivars contributes to environmentally-benign agriculture by lowering the input of chemicals and energy. A very close relation between drought tolerance and nutrient uptake in chickpea cultivars persuaded us to suggest that drought tolerant cultivars are able to translocate more nutrients from roots into the shoots than the drought susceptible cultivars.

Little information is available regarding genotypic variation for drought tolerance in chickpea (Leport et al. 1999, Anbessa and Bejiga 2002). However, there are some studies explaining the relationship between nutrient uptake and drought tolerance in faba bean (Xia 1997), in corn (Rafiee et al. 2004) in soybean (Khan et al. 2004, Samarah et al. 2004). As suggested by Garg (2003) the interaction between soil moisture deficits and nutrient uptake is of principal importance, and according to Ali et al. (2002) nutrient acquisition in chickpea needs to be efficient. The same researchers report that nutrient deficiencies cause yield losses of varying magnitude in chickpea, e.g., 22–50% due to Fe, around 10% due to sub-optimal nodulation and hence N deficiency, 29–45% due to P, up to 100% due to B, and 16–30% due to S. Samarah et al. (2004) recently suggested that the uptake of minerals in soybean seed grown under drought stress may have an important role in drought tolerance, but information on chickpea cultivar improvement for higher nutrient-use efficiency under drought conditions is not available at present. This study could help to understand the interactive relationships between nutrient uptake efficiency (N, P, K, Ca, Mg, Fe, Zn, Mn and B) and drought tolerance of chickpea cultivars under drought imposed at different phases of the growth.

In conclusion, drought tolerant chickpea cultivars showed consistently higher nutrient uptake efficiency. The decreases in nutrient uptake, efficiency and GR were generally small in tolerant, but huge in susceptible cultivars. Consequently, the result of the present study suggests that the uptake of mineral nutrients in chickpea cultivars grown under drought stress may possibly have a part in drought tolerance.

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