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Physiological responses of chickpea (*Cicer arietinum*) genotypes to drought stress

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Abstract

In order to evaluate grain yield and physiological traits related to drought tolerance, a field experiment with 35 chickpea genotypes was carried out. Plants were grown either under optimum conditions (irrigated) or drought stress implemented at post-anthesis stage (rainfed conditions). A drought susceptibility index was used as a measure of drought tolerance. Plants were sampled at 50% flowering time for measurement of relative water content, chlorophyll and carotenoid concentrations and ion accumulation (Na^+ and K^+). The results showed that there was wide variation in tolerance to drought stress among chickpea genotypes. Drought-tolerant genotypes had higher relative water content, chlorophyll and carotenoid concentrations and larger K^+ accumulation compared to Na^+. Significant and well-defined relationships between drought susceptibility index and relative water content, chlorophyll and carotenoid concentration, Na and K uptake were found. It was concluded that these parameters could be useful and reliable indices for selection in chickpea breeding for drought tolerance.

Key words: chickpea, *Cicer arietinum*, drought stress, physiological response.
Abbreviations: DSI, drought susceptibility index; RWC, relative water content; RWL, rate of water loss.

Introduction

Chickpea (*Cicer arietinum* L.) is grown in many parts of the world and yields a total of about 9.8 M t from an area of 11.1 M ha (FAO STAT 2009). Despite the high yield potential of chickpea of over 4000 kg ha^{-1} (Singh 1987; Singh 1990), the actual yields are significantly lower considered to be due to a combination of biotic and abiotic stresses (Singh 1993).

Among the major chickpea producer countries, India, Pakistan, Turkey and Iran, most growing areas are classified as arid or semi-arid (Anonymous 2011). In these regions, chickpea is generally grown under rainfed conditions either on stored soil moisture in subtropical environments with summer-dominant rainfall or on current rainfall in winter-dominant mediterranean-type environments. In both environments, nonirrigated chickpea plantations suffer yield losses from terminal drought (Yadav et al. 2006; Toker et al. 2007). Deleterious responses to drought can include reduction of growth, decrease in chlorophyll, increase in hydrogen peroxide, which causes lipid peroxidation and consequently membrane injury (Mukherjee, Choudhuri 1983).

It is recognized that resistent plants under water stress conditions develope various physiological and biochemical responses of adaptive nature. These include changes of water use efficiency, pigment content, osmotic adjustment and photosynthetic activity (Dhanda et al. 2004; Serraj et al. 2004; Benjamin, Nielsen 2006; Kalefetoğlu, Ekmekçi 2009; Praba et al. 2009). These mechanisms play a key role in preventing membrane disintegration and provide tolerance against drought and cellular dehydration (Hanson, Hitz 1982; Bohnert, Jensen 1996; Mahajan, Tuteja 2005). High relative water content (RWC) and low excised-leaf water loss (rate of water loss, RWL) are associated with drought resistance, and these parameters have also been proposed as more valuable indicators of plant water status in comparison to other water potential parameters under drought stress (Keles, Oncel 2004).

Photosynthetic pigments play an important role in light harvesting and dissipation of excess energy. It is known that the content of both chlorophyll a and b changes under drought stress (Farooq et al. 2009). Carotenoids participate in energy dissipation and can aid plant resistance against drought stress (Gunes et al. 2008). The above parameters have been used as screening techniques separately in different crops, but their relative efficiency has not been evaluated. As a major crop, wheat has gained special attention with respect to morphological and physiological characters and traits affecting drought tolerance, but there is not enough information for chickpea about the

relevant parameters and their relationships with drought susceptibility index (DSI) among chickpea cultivars.

As mechanisms of responses to drought stress varies with genotypes and growth stages of individual plants (Ashraf, Harris 2004), it would be much more valuable if biochemical indicators could be specified for individual crop species. Knowledge on interrelationships among various physiological responses to dehydration can offer insight for developing usefull strategies to improve drought stress tolerance in chickpea. The measurement of each of these variables is demanding in terms of time and resources. The identification of suitable plant characters for screening large numbers of genotypes, in a short time at critical stages of crop growth, with the aim of selecting drought tolerant cultivars, remains a major challenge to the plant breeder. The objectives of the present investigation were (i) to determine the magnitude of genetic diversity in morpho-physiological traits related to drought tolerance in chickpea inbred lines and (ii) to explore relationships among potentially useful traits to be used in breeding programs for drought tolerance.

Materials and methods

Thirty five kabuli chickpea (*Cicer arietinum* L.) accessions were chosen for the study based on their reputed differences in yield performance under irrigated and non-irrigated conditions (Table 1). Experiments were conducted at the experimental field of Islamic Azad University of Sanandaj, in Kurdistan province (northwest of Iran) in 2009. Seeds were hand drilled and each genotype was sown in three rows of 2.0 m, with row to row distance of 0.3 m. The experiment was laid out in randomized complete block design with three replications. Sowing was performed in 25 February for all treatments. In a non-stress (control) treatment, watering (50 mm) was applied on 15 March, 7 April, 15 April, 23 April, 2 May and 15 May (20, 42, 50, 58, 60 and 75 days after sowing), but for the stress treatment watering was performed on 15 March and 7 April. All measurements with fresh material were done from 23 April to 15 May when 50% or more of the plants in a plot flowered. The mean daily evapotranspiration (mm day^{-1}) within the growing season in the region was 1.1 in February, 1.5 in March, 2.1 in April and 4.9 in May. The drought-susceptibility index (DSI) was used as a measure of drought tolerance in terms of minimization of the reduction in yield caused by unfavorable compared to favorable conditions. It was calculated according to Fischer and Maurer (1978) for each genotype:

$$\mathrm{DSI} = \frac{1-(y_s / y_p)}{1-(\bar{y}_s / \bar{y}_p)} \quad (1)$$

where y_s is the yield of cultivar under stress, y_p the yield of cultivar under irrigated conditions, $\bar{y}_s$ and $\bar{y}_p$ the mean yields of all cultivars under stress and non-stress conditions, respectively, and $1-(\bar{y}_s / \bar{y}_p)$ is the stress intensity.

Table 1. Absolute plant yield (g plant^{-1}) in irrigated (Y_i) and non-irrigated (Y_d) conditions, drought susceptibility index (DSI) and relative water content (RWC%) values of chickpea genotypes grown under irrigated (I) and non-irrigated (NI) conditions

No	Genotype	Y_i	Y_d	DSI	Relative water content (%)	
					NI	I
1	FLIP97-706C	5.28	2.58	0.69	51.61	69.77
2	FLIP03-17C	6.36	3.10	0.79	51.16	57.97
3	FLIP03-31C	5.53	1.64	0.91	67.44	71.76
4	FLIP03-63C	4.45	2.92	0.47	62.07	79.66
5	FLIP03-74C	7.97	2.91	1.13	58.06	86.36
6	FLIP03-87C	7.76	2.62	1.15	57.14	65.08
7	FLIP03-128C	6.33	2.72	0.86	56.76	68.42
8	FLIP03-134C	8.55	1.92	1.42	55.88	77.61
9	FLIP03-135C	5.74	2.14	0.86	68.18	79.03
10	FLIP03-141C	5.58	2.55	0.75	58.97	82.67
11	FLIP04-2C	6.97	2.16	1.08	61.29	85.25
12	FLIP04-19C	8.73	2.46	1.36	59.26	73.91
13	FLIP05-16C	9.24	2.29	1.48	63.13	75.86
14	FLIP05-18C	7.01	2.34	1.06	66.67	71.76
15	FLIP05-21C	5.07	2.16	0.73	53.85	60.23
16	FLIP05-22C	6.72	2.88	0.90	68.42	73.53
17	FLIP05-26C	7.55	3.34	0.97	68.69	83.33
18	FLIP05-33C	6.33	1.42	1.10	68.24	76.44
19	FLIP05-40C	4.72	2.31	0.64	69.23	72.97
20	FLIP05-44C	10.85	2.38	1.77	59.46	93.42
21	FLIP05-46C	6.48	2.94	0.85	55.26	66.22
22	FLIP05-58C	4.96	1.53	0.83	59.26	62.03
23	FLIP05-59C	5.77	2.20	0.85	54.81	65.96
24	FLIP05-74C	6.42	3.16	0.80	53.85	61.00
25	FLIP05-87C	7.61	2.71	1.10	57.14	59.46
26	FLIP05-110C	8.93	2.91	1.31	56.10	60.92
27	FLIP05-142C	6.08	3.19	0.73	57.89	71.88
28	FLIP05-143C	6.86	2.26	1.04	62.50	70.31
29	FLIP05-150C	7.15	2.10	1.13	60.71	63.93
30	FLIP05-153C	4.16	2.69	0.46	59.57	64.56
31	FLIP05-160C	6.08	2.38	0.88	58.26	64.77
32	FLIP82-150C	8.60	2.40	1.34	54.55	70.18
33	FLIP88-85C	8.07	3.18	1.10	59.38	65.90
34	FLIP93-93C	7.58	3.32	0.98	56.67	63.89
35	ILC482	7.29	0.23	1.50	58.33	68.83
LSD (0.05%)		1.23	0.97	0.24	4.36	6.18

Six plants were randomly chosen from each plot to measure the number of seeds per plant, number of pods per plant, plant height, time to flowering and mass of 100 seeds. Grain yield (g m^{-2}) was measured by harvesting each plot at crop maturity. Leaf relative water content (RWC) was determined according to Turner (1981), based on the following equation:

(2) RWC = (FM – DM) / (SM – DM) × 100,

where FM is leaf fresh mass, DM is dry mass of leaves after drying at 85 °C for 3 days, and SM is the turgid mass of leaves after soaking in water for 4 h at room temperature (approximately 20 °C). Half of the third (from the top) fully expanded leaf was used.

Samples for chlorophyll and carotenoid determination were taken from soybean leaves using a 0.8 cm diameter cork borer, weighted quickly in pre-weighted clean glass vials and 5 cm^3 of 80% acetone was added to these samples. The leaf material was bleached and decanted off. The optical density was read at λ = 663, 646 and 470 nm using 80% acetone as a blank by a spectrophotometer (Spectronic Genesys-5 Milton Roy). Content of chlorophyll *a*, chlorophyll *b* and carotenoids (μg g^{-1}) was calculated according to Lichtenthaler and Wellburn (1983) using the following formulae:

(3) Chlorophyll $a = 12.21\ OD_{663} - 2.81\ OD_{646}$;

(4) Chlorophyll $b = 20.13\ OD_{646} - 5.03\ OD_{663}$;

(5) Total Chlorophyll = Chlorophyll *a* + Chlorophyll *b;*

(6) Carotenoids = (1000 OD_{470} – 3.27 Chlorophyll *a* – 104 Chlorophyll *b*) / 229

Potassium and sodium concentrations were determined by atomic absorption spectrophotometry (Shimadzu UV-VIS 1201). Potassium- and sodium-uptake efficiency was calculated as the sum of the individual nutrient uptake in drought stress treatment divided on sum of the individual nutrient uptake in the control. Data were analyzed using the SAS programme (SAS Institute, Inc., 1997). Analysis of variance and Duncan's multiple range tests were employed for comparisons of means.

Results

Drought stress reduced the seed yield of all genotypes. Yield reduction of different genotypes varied from 34.3 to 78.1% (Fig. 1). The results indicated the presence of a considerable amount of genotypic variation among the chickpea accessions under drought stress. Genotypes Flip03-63C and Flip05-158C were found to be highly tolerant, with the yield reduction much more lower than average (61.4%). Surprisingly, most of the genotypes showed more than 50% yield reduction under drought stress.

DSI and RWC values of chickpea genotypes grown under optimal and terminal drought stress conditions are given in Table 1. The DSI varied from 0.46 to 1.77 with an average of 0.96. More than 60% of genotypes had a DSI value higher than the average. Drought stress significantly reduced RWC of all genotypes. Drought-induced reduction in RWC occurred to a greater extent in the drought susceptible genotype FLIP03-74C (30%), and to a lesser degree in the tolerant genotype FLIP05-153C (7.8%). The average drought-induced reduction in RWC was 17.37%. All genotypes having low values of DSI in this study had relatively high RWC value.

Total chlorophyll, chlorophyll *a*, chlorophyll *b* and carotenoid concentration of chickpea genotypes grown under irrigated and non-irrigated conditions are given in Table 2. These parameters showed significant changes under drought stress, compared to controls ($P < 0.05$). Also, the total carotenoid concentration was significantly lower in most chickpea genotypes. The genotypes Flip03-63C, Flip03-87C, Flip05-59C, Flip05-74C, Flip05-143C and Flip05-153C showed less reduction in pigments compared to others. Some genotypes (Flip03-128C, Flip03-135C, Flip04-2C, Flip05-21C, Flip82-150C and Flip88-85C) showed high pigment concentrations in drought stress compared to the normal condition. Regression equations and correlation coefficient between DSI and estimated parameters are given in Table 3. There was significant positive correlation between DSI and total chlorophyll, chlorophyll *a* and chlorophyll *b*. Drought resistant genotypes had high value for these parameters in both conditions or at least had a least reduction in stress condition.

There was significant positive correlation between chlorophyll and carotenoid concentration in both treatments (Table 4). Sodium (Na) and potassium (K) uptake for both treatments also showed significant positive correlation, while in non-irrigated conditions chlorophyll and carotenoid concentration showed negative correlation with potassium uptake (Table 4). Terminal drought stress significantly decreased Na and increased K uptake in plants (Table 5). The genotypes considerably differed in respect to Na and K uptake in control and stress conditions. Calculated Na and K uptake efficiency of genotypes varied between 73.13 to 96.89%, and 53.79 to 95-88%, respectively. DSI and Na and K uptake under drought stress ($r = 0.456^*$ and $r = 0.372$, respectively) were positively correlated (Table 3). In generally, drought-tolerant genotypes showed lower reduction in K uptake and high level of uptake efficiency (Table 5).

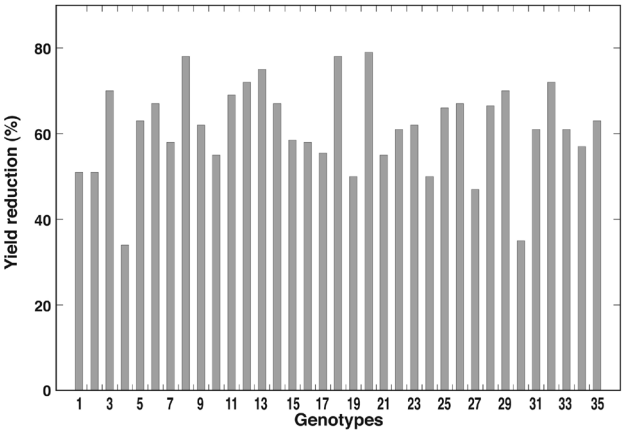

Fig. 1. Yield reduction of chickpea genotypes under non-irrigated conditions.

Table 2. Changes in leaf chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoid concentration (μg g^{-1}) of chickpea genotypes under irrigated (I) and non-irrigated (NI) conditions

Genotype	Chlorophyll *a*		Chlorophyll *b*		Chlorophyll *a* + *b*		Carotenoids	
	I	NI	I	NI	I	NI	I	NI
FLIP97-706C	9.25	5.53	18.87	11.25	28.12	16.78	4.28	2.65
FLIP03-17C	9.35	7.43	19.65	15.14	29.01	22.56	4.72	3.79
FLIP03-31C	6.73	6.24	13.11	10.13	19.35	16.86	3.53	2.53
FLIP03-63C	12.41	8.38	25.89	17.56	38.31	25.94	5.84	4.58
FLIP03-74C	9.49	8.45	20.14	18.25	29.64	26.70	5.07	4.31
FLIP03-87C	4.43	4.07	9.66	8.25	14.09	12.32	2.24	2.06
FLIP03-128C	7.37	4.86	15.19	10.16	22.56	15.02	3.85	2.88
FLIP03-134C	7.10	6.42	14.54	12.80	21.63	19.22	3.84	3.70
FLIP03-135C	6.07	4.88	12.67	10.01	18.74	14.89	3.07	2.63
FLIP03-141C	11.60	5.06	24.99	10.20	36.59	15.26	5.84	2.53
FLIP04-2C	8.17	3.33	16.56	6.57	24.73	9.91	4.19	1.51
FLIP04-19C	9.32	6.36	19.34	12.68	28.67	19.04	4.85	3.06
FLIP05-16C	8.46	5.40	16.96	11.44	25.42	16.83	4.06	2.64
FLIP05-18C	8.03	6.62	16.43	13.34	24.46	19.96	4.18	3.22
FLIP05-21C	5.75	4.47	11.85	9.36	17.60	13.83	2.74	2.49
FLIP05-22C	8.77	8.16	16.24	18.25	24.41	27.01	4.39	4.35
FLIP05-26C	11.24	5.95	23.58	12.00	34.82	17.95	5.89	3.05
FLIP05-33C	6.84	3.91	7.70	14.23	11.61	21.07	3.46	2.17
FLIP05-40C	4.75	4.48	9.04	9.09	13.52	13.84	2.62	2.21
FLIP05-44C	9.16	4.10	18.33	8.31	27.49	12.41	4.81	2.04
FLIP05-46C	6.69	5.26	13.50	10.38	20.19	15.64	3.69	2.23
FLIP05-58C	7.42	5.29	15.17	9.98	22.60	15.27	4.14	2.15
FLIP05-59C	11.27	9.40	24.11	19.85	35.37	29.25	6.10	4.27
FLIP05-74C	8.47	7.73	17.57	15.57	26.03	23.30	4.02	3.40
FLIP05-87C	5.59	5.02	10.77	9.92	16.36	14.95	2.99	2.33
FLIP05-110C	4.50	3.76	9.10	7.25	13.60	11.01	2.60	1.68
FLIP05-142C	10.06	6.66	20.45	12.97	30.51	19.64	4.50	3.43
FLIP05-143C	10.56	10.05	22.03	19.81	32.59	29.86	5.64	3.99
FLIP05-150C	6.69	4.70	13.32	9.60	20.01	14.31	3.50	2.49
FLIP05-153C	8.83	7.76	18.12	15.88	26.95	23.64	4.61	3.87
FLIP05-160C	6.56	5.53	12.58	11.11	19.14	16.64	3.07	2.95
FLIP82-150C	10.35	4.83	21.17	12.20	31.52	17.03	4.23	2.91
FLIP88-85C	8.93	6.12	19.08	12.80	28.01	18.92	4.67	2.85
FLIP93-93C	6.31	4.00	13.48	7.92	19.79	11.91	3.24	2.27
ILC482	7.47	6.27	16.05	13.25	23.52	19.52	4.43	3.17
LSD (0.05%)	2.77	2.63	4.11	3.98	5.24	4.89	1.97	2.11

Discussion

Drought is deleterious for plant growth, yield and mineral nutrition (Garg et al. 2004; Samarah et al. 2004) and is one of the largest limiting factors in agriculture (Reddy et al. 2004). In different crops, as well as in chickpea, differential genotypic response to drought stress, as a result of variation in physiological parameters has been reported (Gunes et al. 2006; Gunes et al. 2008).

The physiological changes observed could be the result of deleterious effect of water deficit on important metabolic processes as well as responses of various defense mechanisms by the plant under drought stress. In this study, we tried to explain the responses of the genotypes and discussed some physiological parameters that were affected by drought stress. These parameters were also evaluated as drought tolerance selection criteria.

In general, relative water content (RWC) was higher in drought-tolerant genotypes than susceptible genotypes. The significant correlation between DSI and RWC

Table 3. Regression analysis and correlation coefficient between DSI and estimated physiological parameters in chickpea under terminal drought stress condition. *, significant at 0.05; **, significant at 0.01; ns, non-significant

Relationships	Equation	*r*
DSI / RWC	Y = 0.845x + 60.66	0.732**
DSI / chlorophyll *a*	Y = –0.047x + 1.314	0.518*
DSI / chlorophyll *b*	Y = –4.438x + 17.89	0.472*
DSI / chlorophyll *a* + *b*	Y = 0.014x + 1.288	0.613*
DSI / carotenoids	Y = 0.939x + 4.085	0.312ns
DSI / Na^+	Y = –0.001x + 1.22	0.465*
DSI / K^+	Y = 4.372x + 43.96	0.372ns

permitted to suggest that these parameters may be used as selection criteria for chickpea genotypes in drought-stressed environments. These results are in agreement with Gunes et al. (2008) and Sairam et al. (2000).

Drought stress can also alter the tissue concentrations of chlorophylls and carotenoids (Jaleel et al. 2008; Kalefetoglu Macer, Ekmekci 2009). While increased chlorophyll and carotenoid content under drought stress may be related to a decrease in leaf area, it also can be a defensive response to reduce the harmful effects of drought stress (Farooq et al. 2009).

The total chlorophyll content significantly decreased in all genotypes under drought stress, but the reduction were not as great in tolerant genotypes. Higher level of carotenoid concentration in drought-tolerant genotypes has also been reported (Deng et al. 2003; Kalefetoglu Macer, Ekmekci 2009). Drought-tolerant genotypes accumulated more carotenoids than susceptible genotypes. Accumulation of carotenoids for osmotic regulation in drought-stressed leaves in many crops has been reported (Khan et al. 2001; Gunes at al. 2008).

The results showed a positive correlation between carotenoid concentration and DSI (r = 0.312) (Table 3). Carotenoids have a critical role as photoprotective compounds by quenching triplet chlorophyll II and singlet oxygen derived from excess light energy, thus limiting membrane damage. This area of carotenoid function has been reviewed extensively elsewhere (Pogson et al. 2006; Tas, Tas 2007). In addition, carotenoid accumulation in plants under stress had a positive effect on the RWC. High RWC may result from osmoregulation by osmoprotectants, as carotenoids or sugars are often accumulated in plants subjected to drought stress (Leport et al. 1999; Franca et al. 2000; Gunes et al. 2008).

Decreasing water availability under drought generally results in reduced total nutrient uptake and frequently reduces the concentrations of mineral nutrients in crops (Baligar et al. 2001; Gunes et al. 2006). In the present study, chickpea genotypes showed varied response with respect to nutrient uptake in normal and stress conditions. Drought stress significantly reduced Na and increased K uptake and ion uptake efficiency of genotypes. Drought-tolerant chickpea genotypes in both optimal and stress conditions accumulated more K in their leaves. Results of the present study showed that genotypes estimated as drought tolerant on the basis of lower yield reduction and other morphological characteristics generally had higher individual or total K uptake efficiency rates.

A very close relation between drought tolerance and nutrient uptake in chickpea genotypes allows to suggest that drought-tolerant genotypes are able to translocate more nutrients from roots into the shoots than the drought-susceptible genotypes (Gunes et al. 2006). There are some studies explaining the relationship between nutrient uptake and drought tolerance in chickpea (Gunes et al. 2006), corn (Rafiee et al. 2004) and soybean (Khan et al. 2004).

Table 4. Pearson's correlation coefficients for association among physiological traits of chickpea genotypes under irrigated and non-irrigated conditions. *, significant at 0.05; **, significant at 0.01

Treatment		Chl *a*	Chl *b*	Chl *a* + *b*	Carotenoids	Na^+	K^+	RWC
Irrigated	Chl *a*	1	0.99**	1**	0.98**	0.17	0.07	0.23
	Chl *b*		1	1**	0.99**	0.16	0.09	0.22
	Chl *a* + *b*			1	0.99**	0.16	0.08	0.22
	Carotenoids				1	0.18	0.10	0.23
	Na^+					1	0.73**	0.12
	K^+						1	-0.1
	RWC							1
Non-irrigated	Chl *a*	1	0.99**	1**	0.93**	0.16	-0.07	-0.23
	Chl *b*		1	1**	0.95**	0.18	-0.05	-0.19
	Chl *a* + *b*			1	0.94**	0.17	-0.05	-0.20
	Carotenoids				1	0.12	-0.08	-0.15
	Na^+					1	0.66**	-0.02
	K^+						1	0.05
	RWC							1

Table 5. Changes in sodium (Na^+) and potassium (K^+) concentration in different chickpea genotypes under irrigated (I) and non-irrigated (NI) conditions; values in parenthesis show a nutrient uptake efficiency calculated as [(nutrient uptake in NI) / (nutrient uptake in I) × 100]

Genotype	Na^+			K^+		
	mg g^{-1}		%	mg g^{-1}		%
	NI	I		NI	I	
FLIP97-706C	28.5	37.7	75.60	35.8	51.5	69.51
FLIP03-17C	34.3	46.9	73.13	47.6	55.4	85.92
FLIP03-31C	27.33	30.8	88.73	43.23	47.6	90.82
FLIP03-63C	26.1	30.8	84.74	31.11	35.8	86.90
FLIP03-74C	34.3	37.7	90.98	43.6	47.6	91.60
FLIP03-87C	35.4	41.2	85.92	43.6	59.3	73.52
FLIP03-128C	28.5	35.4	80.51	33.29	35.8	92.99
FLIP03-134C	25.1	32.0	78.44	24.1	43.6	55.28
FLIP03-135C	37.7	40.0	94.25	43.6	51.5	84.66
FLIP03-141C	25.75	30.8	83.60	32.97	35.8	92.09
FLIP04-2C	35.4	43.5	81.38	31.9	59.3	53.79
FLIP04-19C	30.8	34.3	89.80	37.87	39.7	95.39
FLIP05-16C	33.1	35.4	93.50	35.8	47.6	75.21
FLIP05-18C	41.2	45.8	89.96	35.8	51.5	69.51
FLIP05-21C	29.34	35.4	82.88	41.19	43.6	94.47
FLIP05-22C	28.5	35.4	80.51	24.1	39.7	60.71
FLIP05-26C	37.7	40.0	94.25	53.12	55.4	95.88
FLIP05-33C	28.5	30.8	92.53	28	47.6	58.82
FLIP05-40C	33.1	38.9	85.09	39.7	47.6	83.40
FLIP05-44C	31.19	35.4	88.11	43.6	51.5	84.66
FLIP05-46C	35.4	36.6	96.72	43.6	55.4	78.70
FLIP05-58C	33.1	42.3	78.25	35.8	63.2	56.65
FLIP05-59C	34.3	38.9	88.17	43.6	51.5	84.66
FLIP05-74C	29.7	34.3	86.59	31.9	47.6	67.02
FLIP05-87C	27.4	37.7	72.68	35.8	51.5	69.51
FLIP05-110C	34.3	35.4	96.89	40.12	43.6	92.02
FLIP05-142C	31.11	34.3	90.70	39.7	51.5	77.09
FLIP05-143C	30.11	36.6	82.27	43.6	59.3	73.52
FLIP05-150C	32.21	37.7	85.44	39.78	43.6	91.24
FLIP05-153C	26.11	30.8	84.77	37.34	39.7	94.06
FLIP05-160C	37.7	40.0	94.25	39.71	43.6	91.08
FLIP82-150C	36.6	38.9	94.09	43.6	47.6	91.60
FLIP88-85C	30.12	34.3	87.81	35.8	47.6	75.21
FLIP93-93C	32	34.3	93.29	35.8	47.6	75.21
ILC482	26.77	29.7	90.13	38.01	39.7	95.74
LSD (0.05%)	1.64	1.83		2.78	3.13	

Water deficit stress is one of the major limitations to agricultural productivity worldwide and a possible solution to this is to improve drought tolerance of crop varieties through breeding. To achieve this goal, a set of reliable traits that can be rapidly and relatively inexpensively screened is needed. Although all the traits and techniques evaluated in this study were reliable in distinguishing between tolerant and susceptible chickpea genotypes, nutrient uptake efficiency and RWC seem to be the most promising for rapid and cheep screening for drought tolerance.

As chickpea is a short cycle crop, the best responses for screening of drought tolerant genotypes could be achieved after anthesis under terminal drought stress during the pod filling growth phase.

In conclusion, large genotypic variation was found among the chickpea germplasm tested for drought tolerance, which underlines the usability of this collection for applied breeding programmes. With the present results, it can be concluded that drought stress retards the growth and metabolic activity of different genotypes of chickpea. Based on analysis of 35 chickpea cultivars, we concluded that there was substantial variation in tolerance to drought within chickpea cultivars. Drought-tolerant cultivars had higher RWC, chlorophyll, carotenoid and ion uptake (Na^+ and K^+) efficiency in comparison to drought-susceptible cultivars. These parameters showed considerable variability and heritability under drought stress conditions. This study may help understand some adaptive mechanisms developed by chickpea cultivars and contribute to identify useful traits for chickpea breeding programmes.

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