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Evaluation of grain filling rate, effective grain filling period and resistance indices under acclimation to gradual water deficit stress in chickpea cultivars

Nahid Niari Khamssi[*1], Kazem Ghasemi Golezani[2], Abdollah Najaphy[3], Saeed Zehtab[2]

[1*] Department of Agronomy and Plant Breeding, Faculty of Engineering, Islamic Azad University, Kermanshah Branch 6715685415, Iran

[2] Department of Agronomy and Plant Breeding, Faculty of Agriculture, Tabriz University, Tabriz 5168678531, Iran

[3] Department of Agronomy and Plant Breeding, Faculty of Agriculture, Razi University, Kermanshah 6715685415, Iran

***Corresponding author: khamssi@gmail.com**

Abstract

Two field experiments were carried out in 2007 and 2008, to investigate grain filling rate (GFR), effective grain filling period (EGFP) and resistance indices of three chickpea cultivars (Hashem and Arman from kabuli and Pirooz from desi type) under well watering (I_1: 70mm evaporation from class A pan), gradual water deficit (I_2 and I_3: 70…90…110…130 and 70…100…130mm evaporation, respectively) and water deficit (I_4: 130mm evaporation). GFR, EGFP, grain yield (GY) and biological yield (BY) were significantly affected ($P<0.05$) by irrigation treatments. Cultivars differed significantly for GFR, EGFP and GY. Interactions of year × cultivar for GY and BY were significant. The pattern of seed dry weight accumulation followed similar two-linear models in the three cultivars under four irrigation treatments. C_3 (Arman) had the highest GFR and GY among the cultivars, and had significant differences with C_1 (Hashem) and C_2 (Pirooz). BY was not different among cultivars. EGFP of C_2 (desi type) was significantly less than those of kabuli type cultivars. GY had significant positive correlation with GFR and EGFP. It is concluded that GFR and EGFP can be reliable criteria for selecting high yielding chickpea cultivars under water deficit conditions. Arman had the highest Y_P, Y_S, STI, MP and GMP, therefore this cultivar had higher grain yield under both water deficit and well watered conditions.

Keywords: Gradual water deficit; Grain yield; Grain Filling Rate; Effective Grain Filling Period

Abbreviations: GFR: Grain filling rate; EGFP: Effective grain filling period; GY: Grain yield; BY: Biological yield; Yp: Yield under well watered conditions; Ys: Yield under water deficit conditions; STI: Stress tolerance index; MP: Mean productivity; GMP: Geometric mean productivity

Introduction

Water deficit is a major constraint which reduces the productivity of crops. It is known that chickpea thrives well under drought conditions. However, there is a greater variability for yield performance of different chickpea genotypes under water deficit stress. Attempts to measure the degree of tolerance with a single parameter have been limited because of the multiplicity of the factors and their interactive contributing to drought tolerance under field conditions (Paramesh & Salimath, 2008). In the western part of Iran, chickpea is sown in early March and water deficit during late vegetative and reproductive stages is one of the most important limiting factors for production of this crop in the region. The severity of water stress is varied from year to year, depending on the amount and distribution of rainfall. Supplementary irrigations at critical stages of crop growth and development can improve chickpea yield substantially (Soltani et al., 2001). Crop production would be greater in many cropping regions if more water was available for crop growth. Water is essential to plant growth because it provides the medium within which most cellular functions take place (Condon et al., 2002). Increasing crop tolerance to water limitation would be the most economical approach to enhance productivity and reduce agricultural use of fresh water resources. To survive against the stress, plants have involved a number of morphological, physiological and biochemical responses (Xiong et al., 2006; Gao et al., 2008). In chickpea, genotypic differences for leaf photosynthesis, dry matter accumulation and redistribution, osmotic adjustment, rate and duration of seed filling have been observed (Davies et al., 1999; Leport et al., 1999), but have not been reliably related to yield under terminal drought (Basu et al., 2007; Turner et al., 2007). Low leaf photosynthetic rates during seed filling are thought to be the major cause of reduced seed size with water shortage (Singh et al., 1987; Leport et al., 1998). It is considered essential to enhance the adaptation of varieties to drought prone environments via both genetic and agronomic approaches. The acclimation of a crop variety is the ability of that variety to perform and produce to its maximum in a particular environment (Yadav et al., 2004).Water limitation in the West and North-West of Iran gradually increases during plant growth and development, particularly under rain-fed conditions. Therefore, this study was carried out for the first time to investigate the acclimation of desi and kabuli type chickpea cultivars to gradual water deficit conditions via evaluation of grain growth characteristics, grain yield and resistance indices.

Table 1. Combined analysis of variance of the effects of gradual irrigation levels on four traits of three chickpea cultivars

Source	Df	GFR	EGFP	GY	BY
Year (Y)	1	0.28	0.65	57478.5	99629
Rep/Y	4	9.12	186.6	1266.3	157901.5
Irrigation (I)	3	4.65*	229.6*	56755*	513480.6*
Y×I	3	0.39	30.2	6002.4	66508.1
Ea	12	2.23	60.2	7124.9	91119
Cultivar (C)	2	3.69*	1479.2*	94483.3*	1939124
I×C	6	3.02	83.5	6062.1	56901.4
Y×C	2	0.46	27.05	94351**	2479575**
Y×I×C	6	0.48	11.31	5838.1	79354.1
Eb	32	2.76	87.03	6190.7	77445.6
CV (%)		20.7	24.9	36.48	23.62

GFR: Grain filling rate, EGFP**:** Effective Grain filling period, GY: Grain yield, BY: Biological yield
*,**significant at $P<0.05$ and $P<0.01$, respectively

Table 2. Mean values of analyzed traits for three chickpea cultivars under four gradual irrigation levels.

Treatment	GFR (mg.day^{-1})	EGFP(day)	GY (g.m^{-2})	BY(g.m^{-2})
Irrigation				
I_1	11.63a	15.6a	291.24a	994.2a
I_2	11.11a	15.4a	220.3ab	760.6ab
I_3	11.09a	15.6a	215.78ab	681.4ab
I_4	10.09b	14.7b	156.77b	603.3b
Cultivar				
C_1	10.47b	15.4ab	205.26b	993.8a
C_2	10.43b	14.7b	158.81b	443.5a
C_3	11.73a	16.1a	282.99a	842.5a
Year				
2007	11.17a	15.43a	243.94a	772.7a
2008	11.09a	14.22a	187.44a	797.1a

Different letters in each column for each factor indicating significant difference at $P<0.05$. I_1, I_2, I_3, I_4: 70; 70…90…110…130; 70…100…130 and 130 mm evaporation from class A pan, respectively. C_1=Hashem, C_2=Pirooz, C_3=Arman

Table 3. Mean values of grain yield (GY) and biological yield (BY) of chickpea cultivars in two years

Traits	Y_1			Y_2		
	C_1	C_2	C_3	C_1	C_2	C_3
GY (g.m^{-2})	197.2b	259.5ab	275.2ab	213.3ab	58.2c	280.8a
BY (g.m^{-2})	682.8b	725.3b	765.0b	745.6ab	526.7c	780.9a

Different letters in each row for each trait indicating significant difference at $P\leq0.05$. Y_1=2007, Y_2=2008, C_1=Hashem, C_2=Pirooz, C_3=Arman

Results

Analysis of variance

Combined analysis of variance of the data (Table 1) showed that the effects of year on all the measured traits were not significant. Grain filling rate (GFR), effective grain filling period (EGFP), grain yield (GY) and biological yield (BY) were significantly affected by irrigation treatments ($P<0.05$). Cultivars differed significantly for GFR, EGFP and GY while BY was not significantly influenced by cultivar. Interactions of year × cultivar for GY and BY were significant (Table 1).

Mean comparisons

GFR, EGFP, GY and BY decreased, as water limitation increased. This reduction was significant under water deficit (I_4), compared with well watering (I_1) and gradual water deficit (I_2 and I_3) treatments. No significant differences for these traits were recorded among I_1, I_2 and I_3 (Table 2). Arman (C_3) had the highest GFR and GY among the cultivars, so that it had significant differences with Hashem (C_1) and Pirooz (C_2). Biological yield (BY) was not different among the cultivars. EGFP of Pirooz (desi type) was significantly less than those of kabuli type cultivars (Table 2). Mean GY under well-watering (I_1) and gradual water deficit (I_2 and I_3) was not significantly different. However, grain yield per unit area significantly reduced as a result of water deficit stress (I_4). Mean grain yield per unit area for C_3 was 37% and 78% higher than those of C_1 and C_2, respectively (Table 2). GY and BY of C_1 in the first year were slightly, but not significantly, lower than those of other cultivars. In contrast, GY and BY of C_2 in the second year were significantly lower than that of C_1 and C_3. C_3 had the highest grain yield per unit area in both years (Table 3).

Grain dry matter accumulation and drought resistance indices

The pattern of grain dry weight accumulation followed a

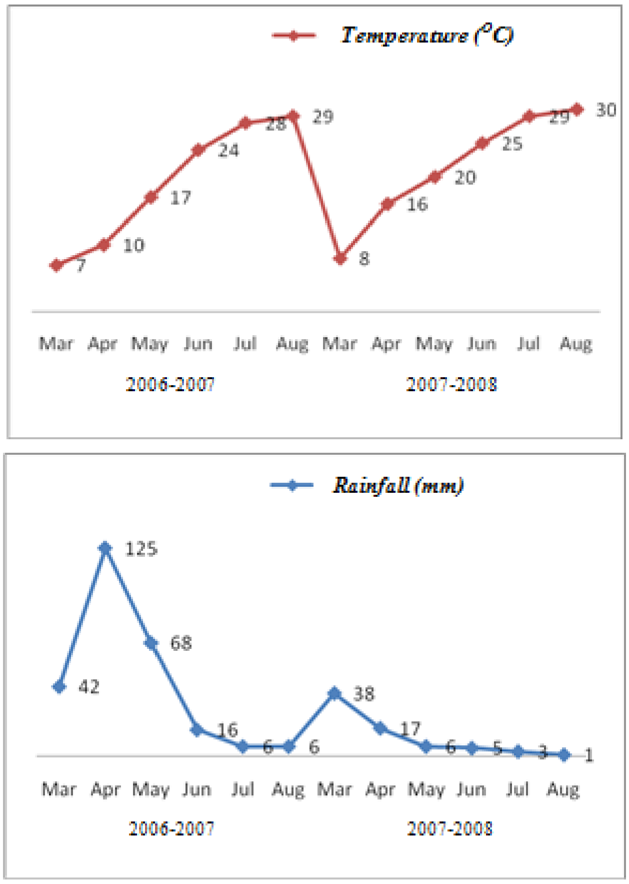

Fig 1. Pattern of monthly rainfall amounts and means temperature recorded during the crop season in 2007 and 2008.

similar linear regression model (two parts) in the three cultivars under four irrigation treatments (Fig. 2). In this model, there was two periods. In the first stage, there was a period of rapid seed filling with an effectively linear increase in dry weight (up to mass maturity or maximum of dry matter). The line slope in the first period showed grain filling rate (GFR). The first stage in this model was longer under I_1, I_2 and I_3 than under I_4 irrigation treatment in all of the three cultivars (Fig. 2). The rate of linear growth was slower in the stressed chickpeas (I_4) than in the well watered (I_1) and gradually watered (I_2 and I_3) chickpeas (Fig 2, Table 2). GY was significantly correlated with GFR (r= 0.547**) and EGFP (r= 0.789**) (Table 4). C_3 had the highest Y_P, Y_S, STI, MP and GMP, therefore this cultivar had higher grain yield in both water deficit and well watered conditions (Table 5). Stress intensity (SI) was estimated to be 0.46. STI, MP and GMP had the highest significant positive correlation with GY (Table 6).

Discussion

Chickpea needs the highest water during flowering, podding and grain filling period, therefore terminal water deficit stress is the most important abiotic stress affecting the crop productivity in Iran (Niari-Khamssi et al, 2010). Gradually increasing irrigation intervals improved chickpea resistance to water deficit as indicated by non-significant differences in GFR, EGFP, GY and BY among I_1, I_2 and I_3 (Table 2). Significant reduction of these traits under I_4 suggests that chickpea plants cannot adapt to water deficit stress, when it is severe and non-gradual. Increasing crop adaptation to water deficit conditions can be the most economic approach to reduce the use of fresh water resources and to improve crop productivity (Xiong et al., 2006). The adaptation of a crop variety is the ability of that variety to perform and produce to its maximum in a particular environment. Acclimation to water deficit stress may also lead to a slightly decrease in efficacy of the other processes like photosynthesis and growth (Rahman 2009). The present study confirmed previous field observations with chickpea that water deficit reduced grain and biological yield (Behboudian et al, 2001; Bahavar et al, 2009). Ghassmi-Golezani and Mardfar (2008) also reported that limited irrigation led to reduction in dry matter accumulation of common bean. The superiority of Arman in producing comparatively greater grain yield could be attributed to higher GFR and EGFP of this cultivar and higher BY in both years. Similar relationship was found for Pirooz in the second year, which had the lowest BY and GY. In general, the impact of climatic conditions on seed development and productivity was not statistically different in the two years (Table 2). Seed growth followed two-linear regression models in both the small-seed desi and the larg-seed kabuli chickpea cultivars because of less seed shattering in the physiological maturity. The duration of first phase in these models was longer in I_1, I_2 and I_3 than in I_4 irrigation treatments for the three cultivars. Therefore the chickpea plants under water deficit treatment (I_4) reached earlier to mass maturity. The rate of seed linear growth was slower in the chickpeas under I_4 than those under both well watering (I_1) and gradual water deficit (I_2 and I_3) conditions, leading to a lower final grain yield under the treatment (Fig. 2, Table 2). Davies et al. (1999) and Kumar and Turner (2009) reported significant reduction in rate of seed growth under terminal drought in chickpea. GY and BY had significant positive correlation with GFR and EGFP (Table 4). Therefore GFR, EGFP and BY could be used as reliable criteria in selection of water stress tolerant chickpea cultivars. A significant positive correlation was found between STI and GY under well watered and water deficit conditions, indicating that the cultivars with high STI and GY under well watering conditions have also high yield under water deficit conditions.

Materials and methods

Site description and plant material

Two field experiments were carried out in 2007 and 2008 at the Research Farm of Kermanshah Azad University (latitude 34º20' N, longtitude 46º20' E, altitude 1351.6 m above sea level). Kermanshah is located in west of Iran and has a mean annual temperature of 13.8ºC and annual rainfall of 478 mm. The soil texture of the research area was sandy-loam. Two kabuli type (Hashem and Arman) and one desi type (Pirooz) chickpea cultivars were planted. The chickpea cultivars were obtained from Dry land Agriculture Research Institute (DARI), Sararoud, Kermanshah, Iran.

Experimental plan and irrigation treatments

The experiments were arranged as split-plot, based on randomized complete block design with three replications. The irrigation treatments were: well watering (I_1: 70 mm evaporation from class A pan), gradual water deficit (I_2 and I_3: 70→90→110→130 and 70→100→130 mm evaporation from class A pan, respectively) and water deficit conditions (I_4: 130 mm evaporation from class A pan) were assigned to main plots and cultivars (Hashem and Arman from kabuli

Table 4. Correlation coefficients of four traits in chickpea cultivars

	BY	GY	GFR	EGFP
BY	1			
GY	0.735**	1		
GFR	0.548*	0.547*	1	
EGFP	0.570*	0.789**	-0.87**	1

BY: Biological Yield, GY: Grain Yield, GFR: Grain Filling Rate, EGFP: Effective Grain Filling Period

Table 5. Grain yield under irrigated and water deficit stress conditions and stress resistance indices based on the two years data.

Cultivars	Y_P	Y_S	SSI	STI	TOL	MP	GMP
C_1	301.9	189.3	1.26	0.45	112.5	214.3	195.5
C_2	186.6	159.5	0.6	0.33	27.11	161.1	159.1
C_3	385.1	247.9	1	0.95	137.1	296.6	283.1

C_1=Hashem, C_2=Pirooz, C_3=Arman , Yp: grain yield under well watered conditions, Ys: grain yield under water deficit conditions, SSI: stress susceptibility index, STI: stress tolerance index, TOL: tolerance, MP: mean productivity, GMP: geometric mean productivity

Table 6. Correlation coefficients of grain yield under irrigated and water deficit stress conditions with stress resistance indices in the three chickpea cultivars.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)Y_P	1						
(2)Y_S	0.961*	1					
(3)STI	0.907*	0.988*	1				
(4)SSI	0.673	-0.844*	-0.300	1			
(5)TOL	0.913*	-0.766	0.658	0.915*	1		
(6)MP	0.976*	0.998*	0.976*	-0.498	0.804*	1	
(7)GMP	0.946*	0.988*	0.994*	-0.399	0.734	0.993*	1

*, significant at P<0.05

type and Pirooz from desi type cultivars) were allocated to sub plots. Seeds were sown in six rows of 6 m length, spaced 25 cm apart (64 seeds per m^2) in the two years in early March. The size of main plots and sub plots were 36 and 12 m^2, respectively. Fertilizers were applied prior to sowing of 20 and 30 kg/ha for N as urea and P as TSP, respectively.

Seeds were pretreated with Mancozeb to minimize the probability of seed- and soil-borne diseases. All plots were irrigated twice after sowing and subsequent irrigations were applied according to the treatments by furrow method. The plots under I_1 irrigation treatment received adequate water, and in gradual water deficit treatments (I_2 and I_3), water deficit increased progressively with the increasing irrigation intervals based on evaporation amount from the pan. In the two treatments (I_2 and I_3), the plants were irrigated after 70 mm evaporation from the pan in the first time after emerging. The second, third and forth irrigations in I_2 were applied after 90 mm, 110 mm and 130 mm evaporation, respectively. Irrigations intervals were increased in I_3 so that second and third irrigations were applied after 100 mm and 130 mm evaporation from the pan, respectively. The plots under I_4 irrigation treatments were irrigated after 130 mm evaporation from the pan. The monthly rainfall amounts and mean temperature during the crop season in 2007 and 2008 were given in Fig. 1. The experimental area was hand weeded.

Measurements

At early flowering, four plants from the second and fifth lines were marked. The day of tagging was referred to as 0 day and subsequent days as days after flowering (DAF). Then, ten marked pods per plot were hand harvested five times at six days intervals and brought back to the laboratory. The pods were threshed and grains detached from the pods. Grains dry weight determined after oven drying to constant weight at 75 ± 1^0C. A linear regression model (two parts) was used in order to estimate and analyze grain filling parameters:

$$W = \begin{cases} a + bt & t \prec tm \\ a + btm & t \geq tm \end{cases}$$

Where W is grain weight, *a* the intercept, *b* the GFR, *t* the DAF, and *tm* the end of grain filling period (mass maturity time). Effective grain filling period (EGFP) was estimated according to Wang et al. (1999) as maximum grain weight (MGW) / grain filling rate (GFR).

Drought resistance indices were calculated based on grain yield under water deficit stress (I_4) and well watered (I_1) conditions using the following relationships:

$$SSI = \frac{1 - (Y_S / Y_P)}{1 - (\bar{Y}_S / \bar{Y}_P)}$$ (Fischer and Maurer, 1978)

$$TOL = Yp - Ys$$ (Rosielle and Hambline, 1981)

$$MP = \frac{Y_S + Y_P}{2}$$ (Rosielle and Hambline, 1981)

$$GMP = \sqrt{Ys \times YP}$$ (Fernandez, 1992)

$$STI = \frac{Y_S \times Y_P}{\bar{Y}_P^{\,2}}$$ (Fernandez, 1992)

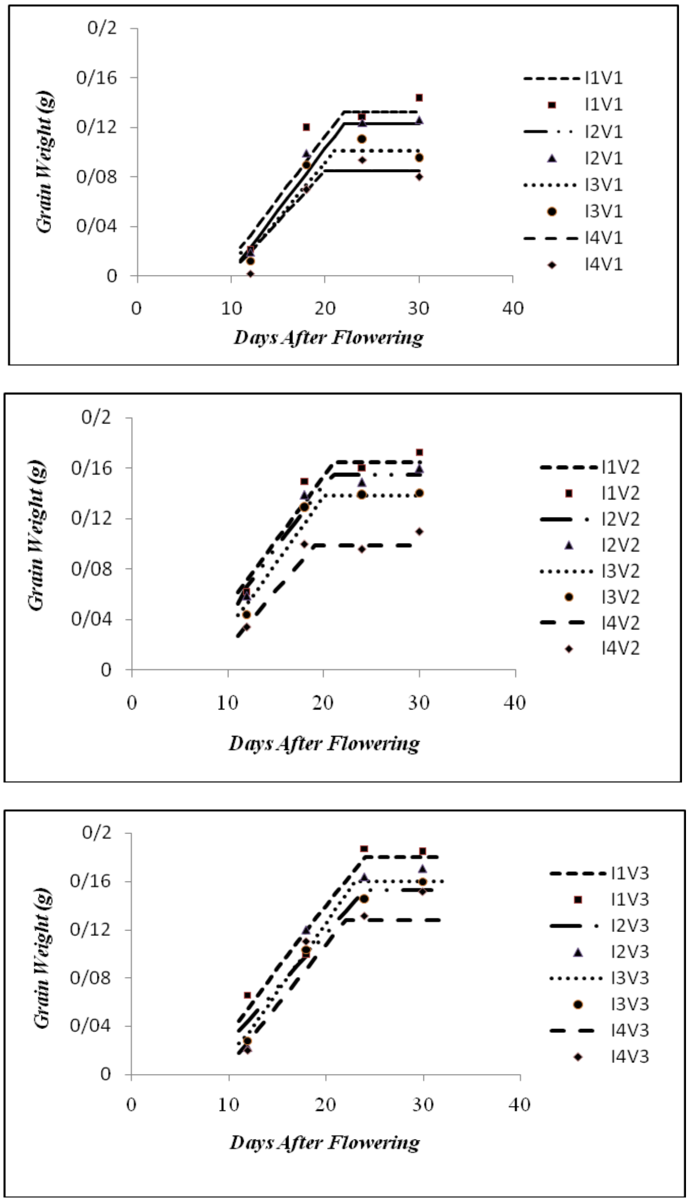

Fig 2. Changes with days after flowering in grain weight in three cultivars Hashem (C_1), Pirooz (C_2) and Arman (C_3) under I_1 (■), I_2 (▲), I_3 (•) and I_4 (♦) irrigation treatments (I_1, I_2, I_3, I_4: 70; 70…90…110…130; 70…100…130 and 130 mm evaporation from class A pan, respectively).

Where Ys is the yield under stress, Yp the yield under irrigated condition, $\overline{Ys}$ and $\overline{Yp}$ the mean yields of all cultivars under stress and well watered conditions, respectively, and $1-\left(\frac{\overline{Ys}}{\overline{Yp}}\right)$ is the stress intensity (SI).

At maturity, plants in 1 m^2 of middle part of each plot were hand harvested and brought back to the laboratory. The pods were then removed, threshed and grains detached from the pods and subsequently grain yield per unit area for each plot was determined.

Statistical analyses

Combined analysis of variance appropriate to the split plot design was carried out using SAS software (version 9.1), general linear method (GLM) procedure. Years were considered as random effects, while irrigation treatments and varieties were fixed in the model. Duncan test was used to compare the differences between means of irrigation levels, varieties and interactions of the two factors at $P<0.05$.

Correlation coefficients between the traits were calculated by SPSS software.

Conclusion

Progressively increasing irrigation intervals can help the chickpea plants to adopt water stress and prevent significant reductions in GFR, EGFP, BY and grain yield per unit area. Grain filling rate, effective grain filling period and biological yield were closely related with grain yield and could be reliable indices for selecting high yielding chickpea cultivars. STI, MP and GMP showed that Arman is a superior cultivar under both well watered (non stress) and limited irrigation (stress) conditions.

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References

Bahavar N, Ebadi A, Tobeh A, Jamaati-E-Somarian SH (2009) Effects of mineral nitrogen on water use efficiency of chickpea under water deficit condition. Res J Environ Sci 3(3): 332-338.

Basu PS, Berger JD, Turner NC, Chaturvedi SK, Ali M, Siddique KHM (2007) Osmotic adjustment of chickpea is not associated with changes in carbohydrate composition or leaf gas exchange under drought. Ann Appl Biol 150: 217-225.

Behboudian MH, Qifu M, Turner NC, Palta JA (2001) Reactions of chickpea to water stress: yield and seed composition. J Sci Food Agri 1288-1291.

Condon AG, Richards RA, Rebetzke GJ Farquhar GD (2002) Improving intrinsic water use efficiency and crop yield. Crop Sci 42: 122-131.

Davis SL, Turner NC, Siddique KHM, Plummer JA, Leport L (1999) Seed growth of desi and kabuli chickpea in a short-season Mediterranean-type environment. Aust J Agric Res 39: 181-188.

Fernandez GCJ (1992) Effective selection criteria for assessing plant stress tolerance. Paper presented at the proceeding of symposium, Taiwan. 13-18 Aug. 1992. pp. 257-270.

Fischer RA, Maurer R (1978) Drought resistance in spring wheat cultivars. I. Grain yield responses. Aus J Agric Res 29: 897-0912.

Gao WR, Wang XSH, Liu P, Chen Ch, Li JG, Zhang JS, Ma H (2008) Comparative analysis of ESTs in response to drought stress in chickpea (*Cicer arietinum* L.). Biochem Biophysic Res Commun 376: 578-583.

Ghassemi-Golezani K, Mardfar RA (2008) Effect of limited irrigation on growth and grain yield of common bean. J Plant Sci 3(2): 230-235.

Kumar A, Turner NC (2009) Growth and sucrose synthase activity of developing chickpea seeds under field conditions. Aus J Crop Sci 3: 20-27

Leport L, Turner NC, French RJ Tennant D, Thomson BD, Siddique KHM (1998) Water relations, gas exchange and growth of cool-season grain legumes in a Mediterranian-type environment. Europ J Agron 9: 295-303.

Leport L, Turner NC, French RJ, Barr MD, Duda R, Davies SL, Tennant D, Siddique KHM (1999) Physiological responses of chickpea genotypes to terminal drought in a Mediterranian-type environment. Europ J Agron 11: 279-291.

Niari-Khamssi N, Ghassemi-Golezani K, Zehtab S, Najaphy A (2010) Effects of Gradual Water Deficit Stress on Phenological and Morphological Traits in Chickpea (*Cicer arietinum* L.), J Agric Sci Technol, USA 4(5): 95-100.

Paramesh SG, Salimath PM (2008) Field screening of chickpea genotypes for drought resistance. Karnataka J Agric Sci 21 (1): 113-114.

Rahman A (2009) Characterization and molecular mapping of drought tolerance in kabuli chickpea. Ph.D. Thesis, department of Plant Sciences, University of Saskatchewan, Saskatoon.

Rosielle AA, Hamblin J (1981) Theoretical aspect of selection for yield in stress and non-stress environments. Crop Sci 21: 943-946.

Singh DP, Singh P, Sharma HP, Turner NC (1987) Influence of water deficits on the water relations, canopy gas exchange and yield of chickpea. Field Crops Res 16: 231-241.

Soltani A, Khooie FR, Ghassemi- Golezani K, Moghadam M (2001) A simulation study of hickpea crop response to limited irrigation in a semiarid environment. Agric Water Manage 49: 225-237.

Turner NC, Abbo S, Yadava HS (2007) Osmotic adjustment in chickpea results in no yield benefit under terminal drought. J Exp Bot 58: 187-194.

Wang G, Kang MS, Moreno M (1999) Genetic Analysis of grain-filling rate and duration in maize. Field Crops Res 61: 211-222.

Xiong L, Wang RG, Mao G, Koczan JM (2006) Identification of drought tolerance determinants by genetic analysis of root response to drought stress and abscisic acid. Plant Physiol 42: 1065-1074.

Yadav SS, Kumar J, Turner NC, Muehlbaur FJ, Knights EJ, Redden B, Mcneil D, Berger J (2004) Enhancing adaptation of larg-seeded kabuli chickpea to drought prone environments. Crop Sci 44: 134-139.