BREEDING FOR DROUGHT TOLERANCE IN CHICKPEA : A REVIEW

RATHOD, V. B.; PITHIA, M. S.; SOLANKI, H. V. AND MEHTA, D. R.

DEPARTMENT OF BIOTECHNOLOGY
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH – 362 001, GUJARAT, INDIA

E-mail: rathodviraj21@jau.in

ABSTRACT

Scarcity of water is a severe environmental constraint to chickpea productivity. Here, we have reviewed the effects of drought stress on the growth, yield, proline, nitrate reductase activity and relative leaf water content in chickpea. This article also describes the mechanism of drought tolerance in plants on a morphological, physiological and biochemical basis. The major mechanisms include curtailed water loss by increased diffusive resistance, enhanced water uptake with prolific and deep root systems, increased proline content, and smaller and succulent leaves to reduce the transpiration loss. Chickpea drought tolerance can be managed by adopting strategies such as mass screening and breeding and marker-assisted selection. Since last ten years several early to medium late maturing varieties with good level of drought tolerance are released for Central and South zone. It played vital role in increasing the chickpea production from 5.47 to 9.88 million tones.

KEY WORDS: Chickpea, drought, tolerance, yield

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is the third most important pulse crop globally. In India, the area under chickpea was 9.51 million ha with a production of 8.83 million tones and productivity of 929 kg/ha during 2013-14 (Table 1) (Anonymous, 2014). In spite of India being the largest chickpea producing country, a deficit exists in domestic production and demand which is met through imports. This is a major challenge to the chickpea scientific community, policy makers and extension agencies. A combination of productivity enhancement and expansion of area can help to achieve this target. In this context, drought and high temperature tolerant varieties are very important, because about 70 per cent areas are under rainfed condition.

What is drought ? (Figure 1)

Drought: Drought refers to the condition of soil moisture deficiency or water scarcity.

Drought resistance: Drought resistance refers to survival of plant under water deficit or scarcity conditions without injury.

Main features of drought

- Drought is characterized with soil water deficit or low soil moisture.
- About 36 per cent of the land area constitutes arid and semi arid zones. Arid and semi arid areas are more prone to drought.
- Drought leads to reduction in both yield and quality of economic product in crop plants. It has adverse effect on plant growth and development.
- Drought damages chloroplasts and lowers photosynthetic output.

- There is an increase in proline level in the leaves of plants which are subjected to all stresses.
- Drought resistance is a genetically controlled physiological property of plant species.
- The general complexity of drought is often aggravated under the conditions of semi arid tropics by erratic and unpredictable rainfall and by occurrence of high temperature, high level of solar radiation and poor soil characteristics.
- Identifying a plant phenotype which can be used in the breeding programme to transfer drought resistance traits in to cultivars with high yielding genetic back ground.

Mechanisms of drought resistance

Drought escape	Drought susceptible variety performs well in drought environment simply by avoiding the period of drought
Drought avoidance	Ability of plant to retain a relatively higher level of hydration under conditions of soil or atmospheric water stress (Maintenance of turgor and volume) • Maintenance of water uptake • Reduction of water loss • Change in tissue characteristics
Drought Tolerance	Significantly lower level of change is induced in it than those in another genotype when both are subjected to the same level of hydration. • Protoplasmic tolerance

Primary requirements for drought tolerance

- Describing drought prone conditions in precise and quantitative terms, as relevant to chickpea and area affected by drought.
- Generating scientific knowledge and information on chickpea responses to drought and genetics of drought related traits.
- Developing reproducible field and laboratory methods for screening and identifying drought tolerant germplasm.
- Characterizing drought tolerant germplasm for easily identifiable, shoot and root traits, reflective of internal plant mechanisms and process that confers drought resistance.
- Incorporating drought tolerant traits in agronomically useful genetic background using conventional breeding methodology.
- Developing tools for rapid incorporation of traits.

Screening Methods

Laboratory screening

Many attempts to identify genotypic differences in germinability have been made in laboratories, using osmotic solutions. In such attempts with chickpea at ICRISAT, differences in germination between genotypes, as well as within a genotype associated with the seed size, have been detected. For that purpose, osmotic solutions like polyethylene glycol (PEG) was used. The osmotic effect of drought are known to be comparable to true drought effects only under non limiting of water movement where the soil and seed contact is perfect (Sharma, 1973). In field condition, it is difficult to visualize a perfect seed and soil contact. Therefore, instead of osmotic solutions, soils brought to different moisture tensions and packed in seed germination trays at a bulk density of 1.1. Results showed that seedlings failed to emerge in vertisol at soil moisture content below 20 per cent (Saxena *et al.*, 1984).

Field screening

The field testing was conducted on a deep vertisol (field capacity 32% w/w and 220-250 mm water-holding capacity in a profile depth of 2 m) at ICRISAT. The field was uniformly irrigated with an overhead system using perforated pipes. Seeding was then done at a uniform depth of 5 cm on different dates, to obtain contrasting differences in soil moisture contents at the time of seeding. During the course of the experiment, no rainfall was received. Counted numbers of seeds were sown in each subplot. Soil moisture at 0-10 cm soil depth was determined gravimetrically at three places in each replicate plot. The percentages of seedlings that emerged were computed. A significant reduction in seedling emergence occurred when soil moisture content was around 20 per cent. This critical moisture content was similar to the value (21%) obtained in the laboratory experiments (Saxena *et al.*, 1984).

Singh *et al.* (1997) screened the chickpea genotypes for drought resistance by sowing them at different dates of sowing. The results indicated that the genotypic differences in response to drought stress were accentuated when sowing was done 3-4 weeks later than the normal sowing time in spring (Table 2). They also evaluated these lines on the 1-9 scale and estimated the drought susceptibility index for all the lines. Score of less than one indicates resistance. Nineteen lines were considered as relatively drought resistant: ILC 142, -391, -588, -1306, -1799, -2216, -2516, -3550, -3764, -3832, -3843, -4236, FLIP 87-7C, -87-8C, -87-58C, -87-59C, -87-85C, -88-42C, and ICC 4958. Out of these, one line (ILC 142) was rated 3, 14 rated 4, one rated 5, and one line had a rating of 6. Drought susceptibility index was also estimated for all the lines (Table 3). Given that a score of less than one indicates resistance, only four of the 19 resistant lines would have been rated as susceptible on the basis of drought-susceptibility score; and the remainder as drought-resistant. Out of these 19 lines, most of the lines that were identified as drought-resistant produced > 1 t/ha of seed yield under stress conditions and about 2 t/ha under non-stress conditions. Such a material is of particular value for those areas, where long-term average rainfall is less than 400 mm, with large temporal variations. These lines will also be of great use to farmers who have access to supplemental irrigation.

Parameshwarappa and Salimath (2008) screened the chickpea genotypes under filed condition and found that studied that among twelve genotypes, ICC 13124 showed maximum yield levels under moisture stress (990 kg/ha) as well as in irrigated condition (1220 kg/ha) (Table 4). Further, it had highest drought tolerance efficiency (72.46%), least drought susceptibility index (0.76) and minimum reduction in seed yield (18.86%) due to moisture stress. More importantly, it maintained highest values of harvest index under moisture stress (46%) as well as irrigated (52.6%) condition. ICC 4958, ICC 13124 and ICC 867 maintained very low value of membrane injury index. Cultivar ICC 13124 showed minimum reduction in dry matter accumulation in root, leaves and stem due to moisture stress at flowering. On the basis of total dry matter hardly 7.8 per cent reduction was noticed due to stress in ICC 13124. Genotype ICC 1422 was another promising type for minimum reduction in dry matter accumulation followed by ICC 4958 and ICC 2969. The genotype ICC 1422 showed minimum reduction at flowering (32%) followed by ICC 4958 (22.5%). At podding, ICC 1422 (13.7%) and ICC 4958 (12.1%) had minimum losses due to stress in total dry matter. ICC 13124, ICC 1422 and ICC 4958 showed minimum reduction in leaf area due to stress at flowering. ICC 1205 and ICC 11121 showed maximum reduction in leaf area due to stress. At podding, ICC 13124 and ICC 4958 showed minimum reduction in leaf area. In other ancillary characters similar type of trend was noticed. This suggested that the drought stress during generative growth enhanced dry matter allocation to generative organs. The effect of moisture stress on RLWC of genotypes did not show any specific trend. However, ICC 4958 and ICC 10448 showed minimum difference in RLWC under moisture stress and irrigated conditions at flowering and podding stage. The maximum difference in RLWC values due to moisture stress and irrigated situation was shown by ICC 13124. Considering the assimilate partitioning in component traits of chickpea, the genotype ICC 13124 maintained minimum reduction in seed yield due to moistures stress along with least reduction for leaf area at different stages. Further, it had the highest drought tolerance efficiency (DTE), least drought susceptibility index (DSI) and minimum reduction in seed yield due to stress. It also maintained the highest harvest index (HI) under moisture stress and irrigated condition indicated that the genotype ICC 13124 may be rated as drought tolerant genotype for moisture stress condition.

Source of Resistance

Serraj *et al.* (2003) reviewed the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)'s research achievements in the domain of crop drought tolerance and presents future perspectives in the genetic enhancement of crop water use and drought adaptation in the semiarid tropics. Exploration of crop genetic variability and genotype-environment interactions has contributed significantly to developing suitable screening methods for specific drought-tolerant traits. Genetic sources of drought tolerance were also identified at ICRISAT for chickpea (*Cicer arietinum*) (Table 5).

Deshmukh *et al.* (2004) reported that genotype DG 36 showed minimum membrane injury and Pusa 372 showed highest membrane injury, which indicated that DG 36 is drought resistant genotype as the temperature increases there is minimum membrane injury is observed (Figure 3).

Upadhyaya *et al.* (2013) reviewed the information regarding the sources of resistance to drought stress as reported by various workers after evaluating the chickpea mini core collection and reported ICC 283, 456, 637, 708, 867, 1205, 1422, 1431, 1882, 2263, 2580, 3325, 4495, 4593, 5613, 5878, 6874, 7441, 8950, 10399, 10945, 11121, 11944, 12155, 12947, 13124, 14402, 14778, 14799, 14815, 15868 and 16524 amongst *desi* chickpea genotypes and ICC 4872, 5337, 7272, 7323, 8261 and 16796 amongst *kabuli* chickpea genotypes (Table 6), were the resistant genotypes against drought.

Ulemale *et al*. (2013) reported that the vegetative phase governs the overall phenotypic expression of the plant and prepares the plant for next important reproductive phase. The plant height, branches and leaves, all these parts constitute vegetative phase and perform specific functions. On ana average, the per cent reduction due to moisture stress for plant height, primary and secondary branches and leaf area was 30.96, 27.69, 34.23 and 38.22 per cent, respectively (Table 7). The genotypes, Phule G 2008-10 (81.90 cm) and Phule G-2008- 19 (74.70 cm) under non-stress condition and Phule 2008-19 (48.30 cm) and Phule G-0302-26 (46.40 cm) under moisture stress condition recorded maximum plant height, respectively. The genotypes Phule G 2008-10 maintained maximum number of primary branches per plant under moisture stress (10.50) and non-stress (14.50) condition followed by genotypes Phule G-6102 under non-stress (14.00) and Phule G-2008-74 under moisture stress condition

(10.40). The genotype Phule G 0204-4 (19.70), Phule G-2008-74 (18.80) recorded highest number of secondary branches per plant under non-stress condition, whereas genotypes Vijay (12.50) and Phule G 0302-26 (11.70) recorded highest number of branches under moisture stress condition. The genotypes, Vishal (9.01dm), Phule G 0714 (8.68 dm) recorded maximum leaf area under non-stress, while under moisture stress condition, genotypes Phule G-0204-16 (5.24 dm) and Phule G-0204-4 (5.19 dm) recorded highest leaf area. The genotyeps, Phule G 0204-16 and Phule G 0204-4 accumulated higher proline content under irrigated, while genotypes Vishal and Phule G 2008-10 accumulated higher proline content under moisture stress condition. The genotypes, phule G 07102 (2.62) and Vijay (2.42) recorded maximum nitrate reductase activity under non-stress, while genotypes Phule G 0302-26 (1.81) Phule G 0204-4 (1.66) recorded highest nitrate reductase activity under moisture stress condition (Table 8). The relative leaf water content (RLWC) was relatively low under moisture stress as compared to non-stress condition. The genotype, Phule G-6102 maintained maximum RLWC at 50 per cent flowering under stress (61.81%) and non-stress (61.87%) and at pod development stage under non-stress condition (70.16%). In addition to this, Phule G 07102 under moisture stress at 50 per cent flowering (58.17%) and pod development stage (69.82%) and Vishal under non-stress condition (59.40%) at 50 per cent flowering were found promising for maintaining higher RLWC. The genotypes, Phule G 6102 (0.479) and Phule G 07102 (0.473) recorded maximum membrane injury index (MII) under moisture stress condition, whereas the genotype Phule G 07102 (0.406) and Phule G 0302-26 (0.374) recorded maximum MII under non-stress condition (Table 9). Therefore, these genotypes can be used as sources of drought tolerance in further breeding programme for evolving the drought tolerant genotypes in chickpea.

Morphological, Physiological and Biochemical parameters

The performance of promising drought tolerant chickpea accessions evaluated under irrigated (E1) and rainfed (E2) condition during 2006-07 by Parameshwarappa *et al*. (2012) which indicated that under irrigated condition, among the 10 accessions evaluated for days to 50 per cent flowering ICC 13124 recorded 38.4 days compared to the checks A-1 (42 days) (Table 10). Under rainfed situation, ICC 13124 recorded 36.3 days as compared to resistant checks ICC 4958 (40.4 days), ICC 10448 (40.1 days) and standard check A-1 (40.2 days). Among the genotypes tested, ICC 13124 recorded highest seed weight of 36.4 g compared to the check ICC 4958 (31.2 g) under irrigated condition, whereas under rainfed condition, the same genotype recorded highest seed weight of 32.2 g. ICC 13124 recorded highest yield of 30.6 g followed by the resistant check ICC 4958 (21.0 g) under irrigated condition. Under rainfed situation, ICC 13124 recorded highest yield of 24.7 g compared to the resistant check ICC 4958 (18.2 g) and standard check A-1 (16.8 g). Therefore, ICC 13124 is identified as another new source for drought tolerance which can be used in the breeding programme in addition to ICC 4958.

Ghiabi *et al*. (2013) calculated yield components and physio-chemical attributes for all genotypes in both environments. The responses of genotypes at each of the two conditions were different. All the measured traits except leaf proline content under water-stress conditions were lower than those under non-stress conditions. Flip2005-1C, Flip2005-5C and Flip2005-7C showed higher grain yield and its component (Number of pods/plant, seeds/plant and seed weight) in both environment (Table 11). Also, the leaf chlorophyll content, Na^+ and K^+ uptake were decreased in water stress environments compare to irrigated environments. In most of the genotypes prolin content was accumulated higher in water-stress environment. Thus, increased contents specifically of proline are important for stress tolerance. These experiments indicated that high grain yield, number of pods and seeds per plant, seed weight, proline and chlorophyll contents could be used as a selection criterion for higher yield in irrigated and stresses chickpea genotypes. Based on these relations and yield data in stress and non-stress environment, Flip2005-1C, Flip2005-3C, Flip2005-7C and Flip51-87C which exhibited the highest grain yield in both irrigation and rain-fed conditions, were the most drought-resistant genotypes.

Kumar *et al*. (2010) observed that the roots penetrated to a maximum depth of 80 to 121 cm at full bloom stage under rainfed condition (Table 12 and Figure 2). The rooting depth remained higher under rainfed than irrigated environment. Under irrigated condition, the roots were able to grow to a maximum depth of 108 cm in HC-5 and 87 cm in H02-36. The genotypes HC-5 and H02-36 with deep root system were shown to produce high shoot biomass, i.e., 9.5 and 7.7 g/plant and seed yield, i.e., 16.9 and 14.2 g/plant, respectively, under rainfed condition. The results of this study indicated that under rainfed conditions, the genotypes HC-5 and H02-36 showed higher dry matter of roots, rooting depth and root : shoot ratio and these traits were directly associated with seed yield per plant. These genotypes could be utilized in crop improvement programs as sources of chickpea breeding for drought tolerance.

Genetic Variability

Data showed wide range of genetic variability, moderate to high heritability and high genetic advance for yield and its component traits in drought tolerant accessions evaluated by Parameshwarappa *et al*. (2012) under moisture stress and irrigated situations during 2006-07. Higher heritability a coupled with higher genetic advance as percent of mean is observed for pods per plant and seed weight per plant, which indicated that these characters are governed by additive gene action (Table 13). They also showed that higher heritability coupled with higher genetic advance as percent of mean is observed for pods per plant, seed weight and yield per plant, which indicated that these characters are governed by additive gene action. And selection of these characters is efficient (Table 14).

Meena *et al*. (2014) studied the GCV, PCV, heritability (broad sense) and expected genetic advance for nine characters (Table 15). All the characters exhibited narrow differences between GCV and PCV values indicating the greater role of genetic factors on the expression of these traits than the environmental factors. The information obtained on variability showed that the estimates of PCV and GCV were higher for seed yield/plant (38.9 & 37.7 under irrigated condition and 32.8 & 27.0 under rainfed condition) followed by harvest index (30.7 & 28.8 under irrigated condition and 34.2 & 29.3 under rainfed condition) both in irrigated and rainfed conditions indicating existence of enough variability for these traits to operate selection in the desirable direction. Low genotypic and phenotypic coefficient variation was for days to maturity (3.2 & 1.9 under irrigated condition and 3.0 & 2.4 under rainfed condition) followed by plant height (5.4 and 4.6 under irrigated condition and 9.8 & 8.7 under rainfed condition, respectively). The 100-seed weight was the only trait which showed medium phenotypic and genotypic coefficient of variation (13.7 & 12.7 under irrigated condition and 10.5 & 9.4 under rainfed condition, respectively). The rest of the traits have shown high phenotypic and genotypic coefficient of variation (> 20%). High heritability is a good index of the transmission of characters from the parents to their off-springs. In the present study, eight characters recorded high heritability (more than 60 %) under irrigated condition and ten characters under rainfed condition indicating the less influence of the environment over the genotypic effect. While the other two traits namely days to maturity and days to 50 per cent flowering showed moderate heritability values in irrigated and rainfed condition, respectively. The highest heritability was found for the trait seed yield/plant followed by biological yield/plant, number of pods/plant, harvest index and 100-seed weight. The genetic advance measures and predicts the genetic gain under selection. The traits seed yield per plant, biological yield, number of pods per plant and harvest index exhibited high heritability coupled with high expected genetic advance indicating the scope for improvement and genetic gain through the selection of these traits.

Genetics of Drought Tolerance

Meena *et al*. (2006) studied that the ratio of gca to sca variance was less than unity for all the traits which indicated the presence of higher proportion of non-additive genetic components of variation in the material. Non-additive gene action was more important for all the characters under study even in this self pollinated crop. In order to make an effective breeding programme, biparental mating among randomly selected plants in F_2 and subsequent generations would help in pooling the desired genes together to develop pure lines.

Genetic analysis carried out by Farshadfar *et al*. (2008) indicated dominance in the inheritance of grain yield, biological yield, harvest index, seed weight and number of seeds per plant, while over dominance gene action in the number of pods plant, earliness and proline content. Moderate narrow-sense heritability estimates were observed for biological yield, harvest index, seed weight, No. of seed/plant and proline content. Moderate genetic advance for grain yield and proline content indicated that direct and indirect selection through correlated response could be effective.

Breeding Methods

Introduction

Introduced materials have contributed to variety development through selection and hybridization. G 109-1 is a selection from material introduced from Turkey.

Selection

Pureline selection in the local materials has produced several improved varieties. Some examples are: Annigeri, Chaffa, Dahod Yellow.

Hybridization

Pedigree method is mainly utilized for drought tolerant varieties development.

CONCLUSION

From the ongoing discussion, it can be concluded that since last ten years several early to medium late maturing varieties with good level of drought tolerance are released for Central and South zone. It played vital role in increasing the chickpea production from 5.47 to 9.88 million tones.

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Table 1: Area, production and productivity in the year 2013-14

Chickpea	Area (million ha)	Production (million tones)	Productivity (kg/ha)
Gujarat	0.17	0.19	1140
India	9.51	8.83	929

Table 2: Screening of drought resistance genotypes based on seed yield (kg/ha) at four different dates of sowing in chickpea

Entry	Dates of Planting				
	28 February	10 March	20 March	30 March	Mean
ILC 72	485	130	11	7	158
ILC 3279	570	365	76	37	262
FLIP 85-142C	339	150	3	6	124
ILC 1929	1439	1276	948	737	1100
ILV 482	1215	1033	661	444	838
ILC 1919	1043	863	524	652	770
FLIP 87-5C	1281	1126	776	704	972
FLIP 87-59C	1435	1420	935	1189	1245
ILC 6104	1611	1176	893	1007	1172
ILC 6118	1507	1263	789	963	1131
Mean	1065	920	587	559	783
SE± (Dates)	42.92				
SE± (Entry)	67.35				
SE± (Dates across entries)					138.78
C.V. % (Date)					33.58
L.S.D. (0.05) Dates					105.03
L.S.D. (0.05) Entries					132.01

Table 3: Performance of 19 highest yielding drought resistant genotypes under rainfed and irrigated conditions

Entry Name	Days to Flower (Rainfed)	Rainfed Seed Yield	Drought Rating Score[a]	Irrigated Seed Yield (kg/ha)	Drought Susceptibility Index
ILC 142	48	1426	3	2212	0.744
ILC 391	56	1166	5	1988	0.981
ILC 588	50	1113	4	2176	0.986
ILC 1306	54	1352	4	1950	0.716
ILC 1799	54	1135	4	2376	1.033
ILC 2216	51	1141	6	1952	0.695
ILC 2516	51	1171	4	1858	0.853
ILC 3550	50	1135	4	2055	0.810
ILC 3764	53	1246	4	2310	0.674
ILC 3832	52	1200	4	2022	0.975
ILC3843	49	1332	4	2532	0.765
ILC 4236	50	1064	4	2325	1.046
FLIP 87-7C	49	1100	4	2220	0.961
FLIP 87-8C	49	1016	4	2368	0.969
FLIP 87-58C	46	1085	4	2197	1.069
FLIP 87-59C	48	1191	4	2245	0.995
FLIP 88-42C	49	1392	4	2075	1.043
FLIP 87-85C	49	1028	4	1858	0.789
ICC 4958	49	1194	5	1931	0.968
Susceptible controls					
ILC 72	68	74	9	1445	1.644
ILC 1171	75	161	8	931	1.697
Mean of 81 genotypes	-	961.4	-	1854.7	-
SE ±	-	119.2	-	214.4	-
C. V.(%)	-	21.5	-	20.0	-
LSD at P≤ 0.05	-	330.3	-	594.1	-

[a]*Score: 1 = Free from damage; 9 = Plants died without producing any seed*

Table 4: Seed yield (Kg/ha) and drought tolerance related characters influenced by different genotypes

Sr. No.	Genotypes	Yield (kg/ha)		% Reduction	DTE %	DSI %	MII		HI	
		I_0	I_1				I_0	I_1	I_0	I_1
1	ICC 13124	990	1220	18.85	72.46	0.76	0.16	0.14	46.0	52.6
2	ICC 12654	767	984	22.05	69.21	0.78	0.21	0.24	44.2	49.8
3	ICC 1205	734	958	23.58	63.21	0.86	0.19	0.16	46.2	50.6
4	ICC 867	780	1020	23.52	64.90	0.94	0.14	0.22	41.3	50.2
5	ICC 4182	615	924	33.44	60.10	0.98	0.23	0.26	37.5	47.2
6	ICC 5504	912	1213	24.81	58.79	0.88	0.32	0.36	32.5	45.0
7	ICC 1422	940	1158	18.82	62.40	0.79	0.28	0.30	29.9	43.2
8	ICC 2969	681	1090	21.09	67.30	0.83	0.32	0.35	33.4	46.2
10	ICC 9848	770	980	21.42	68.90	0.84	0.26	0.28	36.5	48.1
11	ICC 4958	981	1342	26.90	70.20	0.79	0.18	0.16	45.0	51.1
12	ICC 10448	620	849	26.54	69.40	0.82	0.20	0.22	43.6	49.7
	CD at 5 %	86.6	109.2							
	CV %	9.80	11.6							

I_0 – Moisture stress condition; I_1 – Irrigated condition; DTE- drought tolerance efficiency; DSI- drought susceptible index; MII- membrane injury index; HI- harvest index

Table 5: Examples of putative drought-tolerance traits and genetic sources for chickpea

Traits	Source	Yield Advantage Under Drought	Reference
Phenology: extra-short duration	ICCV 2	Yes	Kumar and van Rheenen, 2000
Large root system	ICC 4958	Yes	Saxena *et al.*, 1993
Fewer pinnules	ICC 5680	Yes	Saxena and Johansen, 1990
Small pinnules	ICC 10480	Yes	Saxena and Johansen, 1990

Table 6: Sources of resistance to drought stress as reported by various workers after evaluating the chickpea mini core collection

Stress	Resistant Genotypes		Reference
	Desi	***Kabuli***	
Drought	ICC 283, 456, 637, 708, 867, 1205, 1422, 1431, 1882, 2263, 2580, 3325, 4495, 4593, 5613, 5878, 6874, 7441, 8950, 10399, 10945, 11121, 11944, 12155, 12947, 13124, 14402, 14778, 14799, 14815, 15868, 16524	ICC 4872, 5337, 7272, 7323, 8261, 16796,	Kashiwagi *et al.*, 2005, 2006b, 2008, 2010; Parameshwarappa and Salimath, 2008; Krishnamurthy *et al.*, 2010; Mulwa *et al.*, 2010; Zaman-Allah *et al.*, 2011a, 2011b

Table 7: Vegetative growth and source parameters influenced by chickpea genotypes due to moisture stress condition

Genotypes	Plant Height (cm)		Primary Branches/Plant		Secondary Branches/ Plant		Leaf Area (dm^2)	
	I_1	I_0	I_1	I_0	I_1	I_0	I_1	I_0
Phule G- 0302-26	60.8	46.4	11.0	9.9	18.5	11.7	6.58	4.07
Phule G -0204-4	50.0	33.4	12.7	9.7	19.7	11.5	6.33	5.19
Phule G- 07102	53.9	40.8	10.2	6.3	14.5	9.6	7.61	4.88
Vishal	54.9	30.8	13.3	6.5	18.1	12.5	9.01	4.76
Phule G- 2008-10	81.9	39.4	11.0	10.5	14.1	10.4	6.01	4.07
Phule G-07101	42.7	33.8	13.1	9.8	14.8	11.0	8.26	5.05
Vijay	33.3	28.9	13.6	9.5	13.8	9.3	7.50	3.53
Phule G-07104	43.4	42.6	11.6	10.0	17.6	11.0	8.68	4.21
Phule G-09103	53.9	28.1	10.9	8.0	13.8	9.2	8.21	3.90
Phule G -2008-19	74.7	48.3	14.5	9.1	15.5	9.8	6.01	2.75
Phule G-2008-74	49.9	36.7	12.5	10.4	18.8	9.2	6.70	3.67
Phule G-0204-16	48.9	32.5	12.8	7.0	14.5	7.7	6.65	5.24
Digvijay	52.9	31.9	12.2	9.5	11.5	8.4	7.11	5.11
Phule G-6102	45.9	28.6	14.0	8.0	13.6	11.0	6.25	5.09
Mean	53.4	35.9	12.4	8.9	15.6	10.2	7.21	4.39
S.E. ±	0.155	1.176	0.650	0.225	0.611	0.489	0.412	0.268
CD at 5%	0.473	3.593	1.988	0.689	1.869	1.495	1.260	0.821

Table 8: Proline content and nitrate reductase activity influenced by chickpea genotypes due to moisture stress and irrigated condition

Genotypes	Proline Content		Nitrate Reductase Activity	
	Irrigated Condition	Moisture Stress Condition	Irrigated Condition	Moisture Stress Condition
Phule G- 0302-26	0.841	6.261	2.18	1.81
Phule G -0204-4	1.003	4.927	2.40	1.66
Phule G- 07102	0.697	6.578	2.62	1.49
Vishal	0.867	8.173	2.28	1.40
Phule G- 2008-10	0.597	7.717	2.09	1.75
Phule G-07101	0.784	5.707	2.28	1.15
Vijay	0.656	6.758	2.42	1.31
Phule G-07104	0.966	4.555	2.20	1.58
Phule G-09103	0.840	4.708	2.11	1.46
Phule G -2008-19	0.735	5.257	2.21	1.25
Phule G-2008-74	0.813	6.641	2.40	1.25
Phule G-0204-16	1.132	6.103	2.13	1.30
Digvijay	0.623	6.688	1.26	1.18
Phule G-6102	0.567	5.897	1.91	1.26
Mean	0.794	6.141	2.17	1.42
S.E. ±	0.031	0.383	0.120	0.101
CD at 5%	0.097	1.172	0.369	0.309

Table 9: Physiological parameters related to drought characteristics as influenced by chickpea genotypes due to moisture stress and irrigated condition

Genotypes	Relative Leaf Water Content (%)				Membrane Injury Index	
	50% Flowering		50% pod Development		50% Flowering	
	I_1	I_0	I_1	I_0	I_1	I_0
Phule G- 0302-26	56.32	43.59	69.26	59.74	0.374	0.441
Phule G -0204-4	43.97	43.19	55.70	53.37	0.257	0.447
Phule G- 07102	61.29	58.17	69.82	64.03	0.406	0.473
Vishal	59.40	56.74	68.73	63.05	0.178	0.350
Phule G- 2008-10	43.12	41.09	57.06	54.09	0.294	0.388
Phule G-07101	58.59	54.44	69.27	64.67	0.221	0.461
Vijay	54.68	54.46	65.49	62.66	0.179	0.380
Phule G-07104	46.98	42.39	64.35	62.36	0.321	0.457
Phule G-09103	52.85	49.11	61.60	59.75	0.150	0.289
Phule G -2008-19	50.51	46.22	61.62	55.86	0.235	0.462
Phule G-2008-74	47.28	46.22	61.86	59.60	0.210	0.315
Phule G-0204-16	52.39	44.77	69.67	59.92	0.321	0.322
Digvijay	53.79	40.36	66.45	63.73	0.219	0.331
Phule G-6102	61.87	61.81	70.16	54.27	0.331	0.479
Mean	52.93	48.75	65.11	59.79	0.264	0.399
S.E. ±	1.160	1.380	2.110	1.380	0.0004	0.007
CD at 5%	3.570	4.230	6.470	4.220	0.0010	0.021

I_1= irrigated condition; I_0= moisture stress condition

Table 10: Performance of promising drought tolerant chickpea accessions evaluated under irrigated (E_1) and rainfed (E_2) condition

Germplasm Accessions	DFF		PPP		SDWT (g)		YPP (g)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
ICC 13124	38.4	36.3	77.5	58.2	36.4	32.2	30.6	24.7
ICC 12654	46.2	40.3	62.3	49.2	15.4	14.2	14.5	11.3
ICC 1205	44.3	44.0	87.0	50.2	20.6	19.5	20.6	16.3
ICC 867	40.7	38.3	48.0	43.2	16.3	15.2	12.4	11.2
ICC 4182	48.5	43.2	52.0	34.4	14.5	12.3	9.9	7.5
ICC 5504	68.4	64.2	43.0	18.8	15.6	14.5	12.4	10.4
ICC 1422	39.9	40.0	52.0	40.0	18.1	18.0	16.5	12.8
ICC 2969	46.4	40.2	43.0	40.2	18.3	15.5	16.6	14.5
ICC 11121	46.7	42.1	53.2	39.2	14.3	14.1	12.5	8.3
ICC 9848	48.4	46.3	75.1	37.0	25.1	22.4	20.4	18.8
ICC 4958 (RC)	42.3	40.4	57.5	57.0	31.2	27.0	21.0	18.2
ICC10448 (RC)	42.0	40.1	63.5	41.2	26.0	24.5	19.5	17.4
A-1 (C)	42.0	40.2	72.0	38.5	19.8	17.8	23.5	16.8
C.D. at 5%	1.1	1.2	8.0	13.4	0.8	0.4	1.7	2.3
C.V. %	7.0	8.3	8.9	17.1	8.9	8.2	9.3	9.2

DFF-days to 50 per cent flowering; PPP- pod per plant; SDWT- seed weight; YPP- yield per plant; RC- resistant check; C- check

Table 11: Mean comparisons of various morphological and physiological traits in chickpea under irrigated and rain-fed conditions

Environ-ment	Genotype	No. of Pods Per Plant	No. of Seeds Per Plant	Plant Yield (g/p)	100-Seed Weight	Leaf Chlor-ophyll	Na^+	Proline	K^+
Irrigated	Flip2005-7C	21.33	16.99	8.90	37.49	37.12	48.38	170.67	54.57
	ILC48	22.33	17.00	4.22	30.80	39.23	48.26	166.9	53.38
	Flip51-87C	30.33	30.17	7.97	26.28	29.32	45.99	174.47	57.35
	Arman	27.83	30.66	7.76	25.33	14.00	33.01	163.57	39.94
	Flip2005-3C	29.83	26.5	8.52	32.04	24.53	38.35	143.7	42.96
	Flip2005-1C	34.99	35.0	10.84	32.62	23.33	51.61	170.06	57.58
	Flip2005-5C	33.49	36.99	9.93	24.11	31.94	48.94	159.00	54.86
Rainfed	Flip2005-7C	9.75	15.76	6.88	17.63	27.36	41.11	218.13	48.06
	ILC482	12.00	9.17	2.92	11.02	26.80	38.63	213.07	48.05
	Flip51-87C	12.37	12.70	4.90	14.20	26.37	39.13	217.20	50.34
	Arman	8.87	9.42	3.35	13.70	12.98	21.13	179.17	31.02
	Flip2005-3C	6.62	9.51	3.58	13.25	18.70	24.38	171.13	36.82
	Flip2005-1C	9.75	18.03	8.04	18.65	13.92	48.34	219.60	44.13
	Flip2005-5C	10.62	14.96	7.73	21.7	19.04	41.63	214.07	45.77

Table 12: Plant water relation parameters and yield attributes at maturity of chickpea genotypes under irrigated (I) and rainfed (R) conditions in microplots

Parameters	T	HC-5	H02-36	H03-56	H04-31	H04-33	H04-45
Rooting depth (cm)	I	108	87	78	70	75	72
	R	121	108	95	86	80	91
Root dry weight (g $plant^{-1}$)	I	5.3	4.8	4.1	2.4	3.0	3.6
	R	8.4	7.0	4.8	4.3	4.6	4.1
Root/Shoot ratio (dry weight basis)	I	0.50	0.70	0.54	0.43	0.47	0.62
	R	0.88	0.80	0.87	0.87	0.86	0.80
Seed yield (g $plant^{-1}$)	I	20.6	18.5	16.8	15.2	17.3	14.3
	R	16.9	14.2	13.4	11.2	13.2	12.5
Relative water content (%)	I	92.0	89.9	88.3	86.2	84.3	84.1
	R	82.0	82.0	80.0	72.4	78.4	77.8

G = Genotype; T = Treatment; NS = Non-significant

Table 13: Genetic variability, heritability and genetic advance for seed yield and its component traits in drought tolerant chickpea accessions evaluated under irrigated and rainfed conditions

Characters	Irrigated Condition				Rainfed Condition			
	GCV(%)	PCV(%)	h^2 (%)	GAM(%)	GCV(%)	PCV(%)	h^2 (%)	GAM(%)
DFF	23.74	23.91	98.59	48.57	24.48	24.55	99.42	21.50
PLHT (cm)	11.34	11.51	97.02	23.00	9.24	13.23	48.73	10.93
PB	13.49	18.39	53.80	22.76	13.59	23.77	32.67	15.45
SB	25.87	28.00	85.34	49.24	22.65	24.56	85.07	41.13
TB	18.56	19.03	95.16	37.32	20.59	20.70	98.97	61.36
PPP	30.49	34.59	77.67	55.36	31.17	39.04	63.74	20.38
SDWT (g)	36.58	36.69	99.35	75.12	33.91	35.31	96.04	67.79
YPP (g)	38.05	39.24	93.98	75.96	41.04	41.16	99.44	44.37

GCV= genotypic coefficient of variation; PCV= phenotypic coefficient of variation; h^2=heritability; GAM= genetic advance as % of mean; DFF= days to 50% flowering; PLHT= plant height; PB= primary branch; SB= secondary branch; TB= tertiary branch; PPP= pods per plant; SDWT= 100 seed weight; YPP= yield per plant

Table 14: Genetic variability, heritability and genetic advance for seed yield and its component traits evaluated under rainfed condition during 2004-05, 2005-06 and irrigated condition during 2005-06

Environments	Characters Under Study	Traits							
		DFF	PLHT (cm)	PB	SB	TB	PPP	SDWT (g)	YPP (g)
2004-05 Rainfed	GCV (%)	16.29	23.07	12.69	19.05	15.92	18.90	34.65	27.85
	PCV (%)	16.30	27.56	24.04	49.91	25.62	29.47	35.35	29.79
	h2 (%)	99.87	70.07	27.87	14.57	38.61	41.13	96.07	87.36
	GAM (%)	99.54	39.80	13.73	14.98	20.37	24.97	69.97	53.63
2005-06 Rainfed	GCV (%)	18.02	15.06	21.29	25.75	33.34	33.17	26.94	32.30
	PCV (%)	19.42	18.29	25.37	26.78	54.37	41.43	27.70	32.34
	h2 (%)	86.10	67.83	70.46	99.80	37.62	64.08	94.59	89.75
	GAM (%)	34.44	25.55	36.82	55.06	42.13	54.70	53.99	66.46
2005-06 Irrigated	GCV (%)	17.39	14.99	24.70	30.17	23.10	38.68	29.58	31.51
	PCV (%)	17.48	15.95	34.17	58.34	24.08	51.33	38.87	35.17
	h2 (%)	98.68	88.24	52.26	26.74	92.40	56.78	57.90	80.29
	GAM (%)	35.65	29.00	36.79	32.13	45.66	60.03	46.35	58.18

DFF= days to 50 % flowering; PLHT= plant height; PB= no. of primary branches per plant; SB= no. of secondary branches per plant; TB= no. of tertiary branches per plant; PPP= no. of pods per plant; SDWT= 100 seed weight; YPP= yield per plant

Table 15: PCV, GCV, heritability and genetic advance for nine characters under irrigated and rainfed conditions

Characters	PCV		GCV		Heritability		GA as % of Mean	
	I	R	I	R	I	R	I	R
Seed yield per plant	38.9	32.8	37.7	27.0	94.0	68.2	75.3	45.2
Biological yield	29.9	36.5	29.0	34.2	94.1	87.8	58.0	65.9
Plant height	5.4	9.8	4.6	8.7	71.1	77.9	7.9	15.8
Pods per plant	23.0	25.6	22.1	24.2	91.5	89.7	43.5	47.2
Days to 50 % flowering	7.3	5.9	6.3	4.4	72.1	55.8	10.8	6.7
Days to maturity	3.2	3.0	1.9	2.4	37.3	65.8	2.5	4.1
Seeds per pod	7.5	11.0	5.9	8.3	61.2	56.4	11.1	11.1
Harvest index	30.7	34.2	28.8	29.3	87.9	73.4	55.7	51.7
100-seed weight	13.7	10.5	12.7	9.4	85.2	80.2	24.1	17.2
Harvest index	-	8.3	-	7.9	-	92.4	-	15.7
Membrane stability index	-	14.9	-	14.5	-	94.8	-	28.9

PCV= Phenotypic coefficient of variance; GCV= Genotypic coefficient of variance

Table 16: Estimates of genetic components of variation and heritability of different traits in chickpea

Characters	σ^2gca	σ^2sca	σ^2E	σ^2A	σ^2D	h^2ns	σ^2gca/ σ^2sca
Days to flower	16.99	68.25	0.11	33.98	68.25	33.20	0.25
Days to maturity	22.49	78.90	0.12	44.98	78.90	36.26	0.29
Plant height (cm)	35.84	120.45	0.52	71.68	120.45	37.21	0.30
No. of branches	4.21	20.55	0.25	8.42	20.55	28.81	0.21
Pods/plant	317.39	1924.05	1.13	634.78	1924.05	24.80	0.17
Biological yield (g)	57.60	702.45	2.42	115.20	702.45	14.05	0.08
Seed yield per plant (g)	87.20	238.05	0.28	174.40	238.05	42.95	0.37
100-seed weight (g)	83.75	94.05	0.06	167.50	94.05	64.03	0.89
Harvest index (%)	94.14	411.30	1.79	188.29	411.30	31.30	0.23
Membrane injury (%)	125.37	220.20	0.66	250.74	220.20	53.17	0.57
Relative water content (%)	41.90	204.90	0.70	83.82	204.90	28.96	0.20

σ^2gca: variance due to general combining ability; σ^2sca: variance due to specific combining ability; σ^2E: variance due to environment; σ^2A: additive variance; σ^2D: dominance variance; h^2ns: heritability in narrow sense

Table 17: Genetic parameters and components of variation for various characters investigated under rainfed condition

Characters	h/d	H_b	H_n	G_A	D	H
GY	3.37	0.59	0.55	15.03	0.467	0.068
BY	1.17	0.57	0.48	7.42	0.46	0.108
HI	7.90	0.66	0.20	10.40	0.0006	0.0028
NPP	3.96	0.70	0.04	7.20	0.152	4.108
SW	-0.15	0.84	0.43	10.40	0.754	1.424
NSP	9.88	0.66	0.30	4.70	0.574	1.372
Earliness	-0.34	0.71	0.27	1.21	1.234	3.856
PC	-0.81	0.65	0.20	14.27	0.582	2.524

GY= grain yield; BY= biological yield; HI= harvest index; NPP= no. of pods per plant; SW= 100 seed weight; NSP= no. of seeds per plant; PC= proline content, h/d= degree of dominance; H_b= broad sense heritability; H_n= narrow sense heritability; G_A= genetic advance; D= additive genetic variance; H= dominance variance

Fig.1: A chickpea crop severely affected By terminal drought stress

Fig.2: Rooting depth of chickpea Genotypes under irrigated (I) and rainfed (R) conditions in microplots at full bloom stage

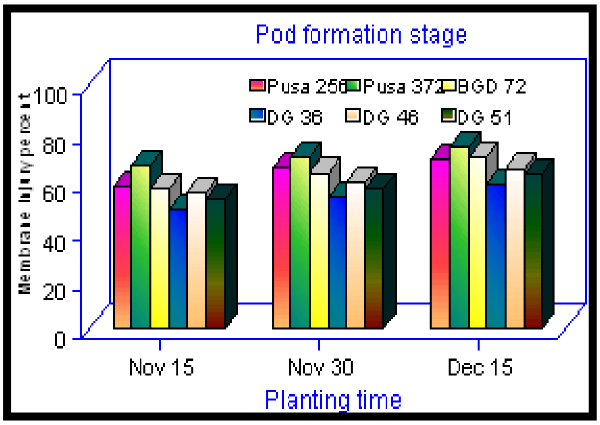

Fig.3:Membrane injury of six genotypes at pod formation stage as influenced by time of planting

[MS received : April 06, 2017] *[MS accepted : April 24, 2017]*