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Correlation of Drought Resistance Traits and Agronomic Traits with Yield in Chickpea (*Cicer arietinum* L.)

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ABSTRACT

The productivity of chickpea (*Cicer arietinum* L.) in arid and semi-arid regions is constrained due to terminal drought. Chickpea genotypes with prolific and deep rooting have been shown to be more adapted to drought. The genetic variability for root morphological traits and various yield and yield components was assessed on 50 chickpea genotypes grown under field conditions laid out in a randomised complete block design with two replications. Considerable variability for various root traits like root length, root volume, root dry weight and root to shoot dry weight and yield components like days to 50% flowering, days to maturity, number of primary branches, number of secondary branches, pods per plant, 100-seed weight and grain yield per plant was observed. Correlation studies indicated a positive association of grain yield per plant with root length, root to shoot ratio, number of primary branches, number of secondary branches and pods per plant both at phenotypic and genotypic levels.

Keywords: root dry weight, root length, root to shoot dry weight, root volume
Abbreviations: GAM, genetic advance as per cent mean; **GCV**, genotypic coefficient of variation; **PCV**, phenotypic coefficient of variation

INTRODUCTION

Chickpea (*Cicer arietinum*) is the world's third largest food legume crop with a total annual production of 8.8 million tons. The cultivated area is over 10 million ha (FAO 2007). It is cultivated in about 50 countries in the arid or semi arid regions. About 90% of world's chickpea is grown under rain fed conditions where the crop grows and matures on a progressively depleting soil moisture profile (Ludlow and Muchow 1990; Krishnamurthy *et al.* 1999) and generally experiences terminal drought which is therefore one of the major constraints limiting chickpea productivity and yield stability (Parameshwarappa *et al*. 2010).

Estimates of yield losses due to drought range from 15-60% which depends on geographical region and length of crop season. Plants adapt to drought environment either through escape, avoidance or tolerance mechanisms (Sabaghpour 2003; Millan *et al*. 2006; Parameshwarappa *et al*. 2010). Drought is an important environmental constraint to which the roots are exposed to during plant growth. Understanding how roots respond to these stresses is crucial for improving crop production under such conditions. Yet investigating roots is a very difficult task and therefore very little is known about the precise role that the roots play in contributing to plant adaptation to hostile environments. It is assumed that the root depth and abundance would contribute to drought tolerance (Price *et al.* 2002; Taiz and Seiger 2006; Kashiwagi *et al*. 2006; Gaur *et al.* 2008; Songsri *et al*. 2008; Bibi *et al*. 2009).

In chickpea, the focus of drought resistance is on the ability to sustain greater biomass production and crop yield under a seasonally increasing water deficit, rather than the physiological aptitude for plant survival under extreme drought shock (Serraj *et al*. 2004). The objective of the present study was to assess the variability for root morphology and to find the association of root traits and yield components.

MATERIALS AND METHODS

Fifty diverse chickpea accessions received from National Bureau of Plant Genetic Resources, New Delhi, India were used for the study which are indicated in **Table 1**. A field experiment was conducted in Karnataka state of the country during *rabi* (*rabi* season in India is the time between Oct-Feb) 2008-2009. The experiment was laid out in a randomised complete block design with two replications. Two rows of each entry were sown at a spacing of 30 cm×10 cm. The plot size was 4 m×0.6 m. To get uniform plant population, one irrigation was provided at the time of sowing while the crop was grown without irrigation for the rest of the growth period. The crop was completely grown under rainfed condition and only 6 mm rainfall was received during crop growth which was too little and as a result of which the crop was under moisture stress during entire growth period thus helping to better assess potential genotypes performing satisfactorily under stress condition.

Plant samples for root measurement were taken from 2 plants in adjacent rows at the late bloom stage and mid pod set growth for each entry on 65th day after sowing. The plants to be sampled were flooded with water and the soil was left for soaking to loosen the soil for a period of about 2 hrs. The plants were removed with one additional plant on the adjacent sides along with the surrounding soil carefully by digging a one meter trench on all four sides of the plants. The roots were then cleaned thoroughly and carefully using a fine jet of water (Kashiwagi *et al*. 2007). The intact root system of each plant was collected and stored in bags for recording observations like root length, root volume, root dry weight and root to shoot dry weight ratio. Root length was measured from the collar region to the tip of the tap root in centimeters (cm). Root volume was determined by immersion technique/water displacement method and expressed in centimeter cubic (cm^3). The root and shoot of each plant after separation was oven dried at 60°C for 144 hrs. Average dry weights of sample were recorded in grams (g). On the 90th day after sowing, 5 plants were sampled out for recording the other plant traits like plant height at harvest (cm), days

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Table 1 List of 50 genotypes used for root study.

ICC 500(1), ICC 5337(2), ICC 5682(3), ICC 5683(4), ICC 5688(5), ICC 5692(6), ICC 5693(7), ICC 5694(8), ICC 5697(9), ICC 5699(10), ICC 5743(11), ICC 5748(12), ICC 5816(13), ICC 6060(14), ICC 6074(15), ICC 10391(16), ICC 6126(17), ICC 7496(18), ICC 7496(19), ICC 7400(20), ICC 7507(21), JG 11(22), Vishal(23), Annigeri-1(24), ICC 10392(25), ICC 10399(26), ICC 10819(27), ICC 10984(28), ICC 10999(29), ICC 11062(30), ICC 12247(31), ICC 12449(32), ICC 12543(33), ICC 12551(34), ICC 13895(35), IC 327130(36), IC 327311(37), IC 327354(38), ICC 5685(39), ICCV 06104(40), ICCV 06106(41), ICCV 06105(42), ICCV 06102(43), ICC 8324(44), ICC 8360(45), JG-2003-109(46), BG-256(47), ICCV -37(48), ICCV 10(49), BGD 134(50).

Table 2 Genetic parameters and significance level of root, yield and yield components

Character	Range		Mean	Significance level	PCV	GCV	h^2(bs)	GAM
Root length (cm)	10.75	24.5	17.712	**	17.196	13.118	0.5819	20.61
Shoot length (cm)	23.75	35.5	29.323	**	9.726	6.726	0.4783	9.58
Root volume (cc)	0.4	3.0	1.191	**	40.297	31.781	0.6220	51.63
Root dry weight (g)	0.4	1.7	0.701	**	34.656	27.549	0.6319	45.11
Shoot dry weight (g)	5.06	16.7	9.802	**	29.562	26.240	0.7879	47.98
Root to shoot ratio	0.0423	0.122	0.0703	**	24.907	21.744	0.7621	39.10
Plant ht. after harvest(cm)	23	35	28.72	**	6.040	4.977	0.6790	12.90
Days to 50% flowering	38	54	45.9	**	7.581	5.938	0.6130	12.82
Days to maturity	69	86	76.9	**	5.975	4.952	0.6868	6.36
No. of primary branches	3	7	4.440	**	21.352	14.244	0.4451	90.69
No. of secondary branches	0	4	1.730	**	63.132	52.719	0.6973	51.24
Pods/plant	6	22	12.110	**	35.922	29.891	0.6924	46.78
100-seed weight (g)	9.4	32.20	21.248	**	23.677	23.051	0.9478	46.23
Grain yield/plant (g)	1.017	3.96	2.666	**	28.866	25.602	0.7867	31.29
Grain yield/plot (g)	72.360	355.12	213.24	**	32.658	22.271	0.4651	13.50

** Significant level at 5%

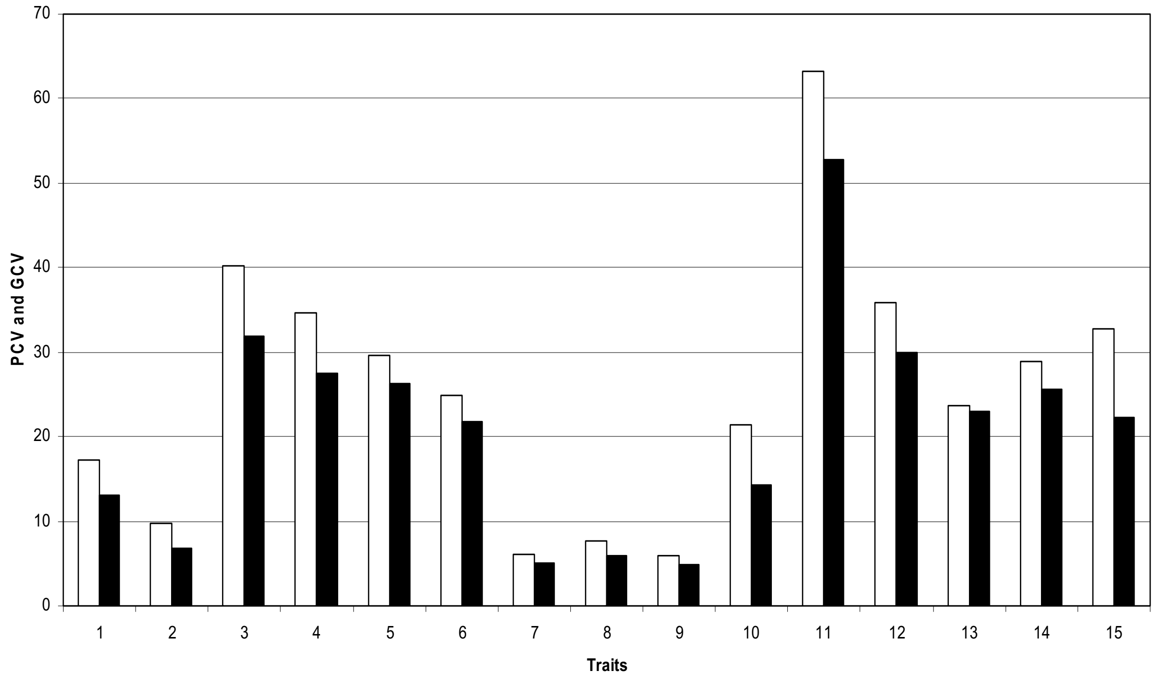

Fig. 1 Phenotypic and genotypic co-efficient of variation for root, yield and yield components in chickpea. 1 = root length, 2 = shoot length, 3 = root volume, 4 = root dry weight, 5 = shoot dry weight, 6 = root to shoot ratio, 7 = days to 50% flowering, 8 = days to maturity, 9 = plant height at harvest, 10 = no. of primary branches, 11 = no. of secondary branches, 12 = pods per plant, 13 = 100-seed weight, 14 = grain yield per plant, 15 = grain yield per plot. Values represent the PCV and GCV values for different traits based on means from a sample of five plants per entry. White bars = PCV; black bars = GCV.

to 50% flowering, days to maturity, number of primary branches, number of secondary branches, pods per plant, 100-seed weight and grain yield per plant. Days from sowing to 50% of the plants in a plot bearing flower was recorded as days to 50% flowering. Total number of days taken from the day of sowing till the day when all the pods had dried was recorded as days to maturity. Shoot length (cm) was measured from tip up to the collar region of the plant at vegetative stage. Plant height (cm) was measured from the ground level to the tip of the shoot. The number of branches arising directly from the main stem was counted which accounted for number of primary branches while those arising from the primary branches accounted for number of secondary branches. Total number of pods of five tagged plants at harvest was averaged to compute pods per plant. One hundred seeds were counted and weighed in grams to compute 100-seed weight. The seed yield of five tagged plants was weighed in grams and the mean value was computed as seed yield per plant

Mean, maximum and minimum value was observed for different traits. Analysis of variance was conducted for mean values of the different characters studied (Sunder Raj *et al*. 1972). Various genetic parameters like phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) (Burton and Devane 1953), heritability in broad sense (h^2bs) (Johnson *et al*. 1955) and genetic advance as per cent mean (GAM) was computed for the traits under study using SPAR 2 (Statistical Package for Agricultural Research at IASRI, New Delhi, India: www.iasri.res.in/iasrisoftware/SPAR2.doc). Phenotypic and genotypic correlation (Al-Jibouri *et al*. 1958) was calculated between different traits as simple correlation of the mean values over two replications of the traits. Path coefficient analysis (Dewey and Lu

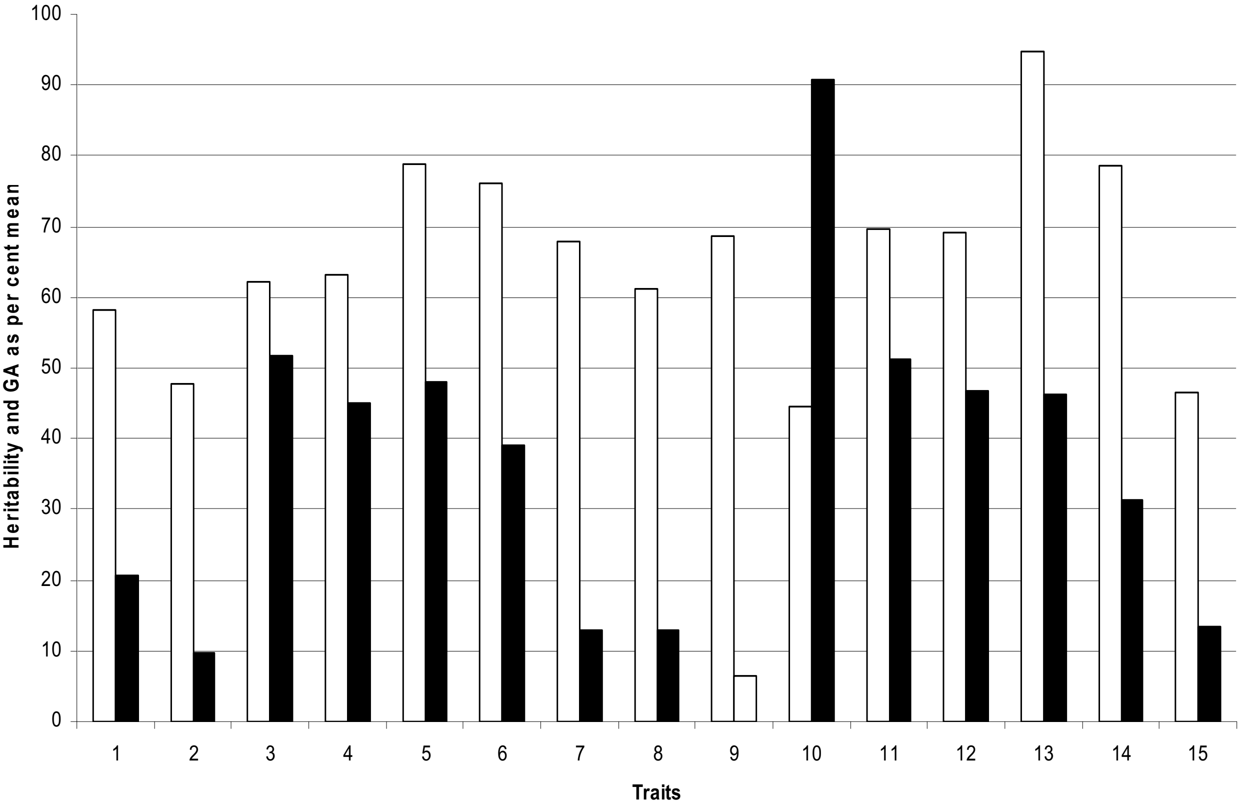

Fig. 2 Heritability and genetic advance as per cent mean for root, yield and yield components in chickpea. 1 = root length, 2 = shoot length, 3 = root volume, 4 = root dry weight, 5 = shoot dry weight, 6 = root to shoot ratio, 7 = days to 50% flowering, 8 = days to maturity, 9 = plant height at harvest, 10 = no. of primary branches, 11 = no. of secondary branches, 12 = pods per plant, 13 = 100-seed weight, 14 = grain yield per plant, 15 = grain yield per plot. Values represent the heritability and GAM for different traits based on means from a sample of five plants per entry. White bars = heritability; black bars = GA as % mean.

1959) was done using the correlation coefficients to ascertain the direct and indirect effects of the root traits and yield components on yield.

RESULTS

Analysis of variance carried out for the germplasm accessions revealed significant differences among genotypes for all the characters studied (**Table 2**). The results with regards to overall mean, range, PCV, GCV, h^2bs and expected GAM for all the characters is detailed in **Table 2** and **Fig. 1**. Histograms in **Fig. 1** show that GCV is less than PCV for all the traits indicating the role of environment in the expression of the traits. The highest heritability was observed for 100-seed weight (0.9478) and lowest was observed for number of primary branches per plant (0.4451). Highest coefficient of variation was observed for the number of secondary branches at the genotypic level (52.72%) and for primary branches at the phenotypic level (63.13%). Genetic advance as percent mean was highest for number of primary branches (90.69%) and was lowest for days to 50% flowering (12.82%) (**Fig. 2**). Higher genetic advance as per cent mean indicates that improvement of such traits through direct selection will be effective.

Among the root traits studied root length was observed highest for ICC 12449 (24.9 cm), root volume for 'ICC 11062' (3 cm^3), root dry weight for 'ICCV 6106' (1.7 g) and root to shoot ratio dry weight ratio for 'ICC 12449' (0.122). For yield components 'ICC 12543' was recognized as early flowering (38 days) and maturing (54 days) entry, 'ICCV 6106' (35 cm) was the tallest genotype of all entries, 'ICC 12449' (7) had maximum number primary branches, 'ICC 11062' (4) had maximum number of secondary branches and pods per plant was highest for 'ICC 10391' (22).

Correlation studies indicated in **Table 3** showed highly significant and positive association for grain yield per plant with root length, root to shoot ratio, number of primary branches, number of secondary branches and pods per plant with values of 0.431 (or 43.1%), 0.894, 0.528, 0.373 and 0.518 at phenotypic level and 0.372, 0.939, 0.612, 0.458 and 0.502 genotypic levels (**Fig. 3**). Significant association with grain yield at phenotypic level was observed for root volume and root dry weight having values of 0.289 and 0.283 and at genotypic level with shoot length (0.314). Significant negative association with grain yield was observed for shoot dry weight with correlation values of -0.630 at genotypic level and -0.417 at phenotypic level.

High positive genotypic correlation was observed for root length with root volume (0.283), root to shoot ratio (0.486), number of primary branches (0.392), number of secondary branches (0.553) and pods per plant (0.336) while negative association was observed for shoot dry weight (-0.393). Root volume showed positive genotypic association with root dry weight (0.351) while root dry weight was highly correlated with shoot dry weight (0.666) and root to shoot ratio (0.314). Shoot dry weight was negatively associated with root to shoot dry weight ratio (-0.471), number of primary branches (-0.640), number of secondary branches (-0.342) and pods per plant (0.480).

Path coefficient analysis indicated in **Table 4** revealed that root length (-0.1008), shoot length (0.0371), root volume (-0.0134) and root to shoot ratio (-0.1480) had low direct effect on grain yield but high direct effect on grain yield was through root dry weight (1.0907) and shoot dry weight (-1.2623), the latter being negative. Root length showed significant association with yield through indirect effect of shoot dry weight (0.4977) and shoot length exhibited association with through root dry weight (0.5165). Root to shoot ratio contributed to yield through indirect effect of several characters like root dry weight (0.3425), shoot dry weight (0.5951), number of primary branches (0.1287) and number of secondary branches (0.1231). Comparatively higher direct effect on yield was through number of primary branches (0.2088), number of secondary branches (-0.2171) and pods per plant (0.2828) apart from root dry weight and shoot dry weight.

Table 3 Genotypic (G) and phenotypic (P) correlation among root, yield and yield components in chickpea.

		X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
X1	G	0.028	0.283*	-0.018	-0.390**	0.485**	0.256	0.106	-0.058	0.392**	0.553**	0.336*	-0.046	0.372**	0.372**
	P	0.046	0.362**	0.197	-0.122	0.423	0.136	-0.117	-0.049	0.306*	0.303*	0.338*	-0.032	0.431**	0.267
X2	G		0.521**	0.473**	0.137	0.355 *	0.379**	-0.276	-0.019	-0.081	-0.222	-0.060	0.141	0.314*	0.293*
	P		0.346*	0.305*	0.149	0.194	0.258	-0.173	0.046	0.041	-0.100	-0.038	0.097	0.219	0.169
X3	G			0.351*	0.146	0.122	-0.175	-0.131	-0.037	-0.035	0.229	0.106	0.026	0.118	0.062
	P			0.484**	0.236	0.270	-0.139	-0.217	-0.003	0.180	0.176	0.262	0.020	0.289*	0.222
X4	G				0.666**	0.314*	0.130	-0.142	0.052	-0.0258	0.010	-0.198	0.131	0.131	0.244
	P				0.685**	0.436**	0.049	-0.229	0.003	0.065	0.067	0.111	0.099	0.283*	0.276*
X5	G					-0.471**	-0.093	-0.048	-0.181	-0.640**	-0.342**	-0.480**	-0.083	-0.630**	-0.421**
	P					-0.322*	-0.089	-0.096	-0.166	-0.299	-0.234	-0.240	-0.066	-0.417**	-0.220
X6	G						0.355*	-0.180	0.212	0.616**	0.500**	0.435**	0.183	0.939**	0.768**
	P						0.197	-0.245	0.142	0.502**	0.410**	0.484**	0.162	0.894**	0.626**
X7	G							0.467**	0.096	0.534**	0.382**	0.381**	-0.394**	0.340*	0.217
	P							0.410**	0.124	0.290	0.366**	0.299*	-0.355	0.187	0.061
X8	G								0.209	-0.119	0.043	0.020	-0.171	-0.086	-0.162
	P								0.158	-0.150	0.051	-0.088	-0.144	-0.202	-0.227
X9	G									**0.046**	**-0.212**	**0.171**	**0.139**	**0.238**	**0.481****
	P									0.144	-0.099	0.119	0.096	0.236	0.236
X10	G										**0.837****	**0.637****	**-0.154**	**0.612****	**0.537****
	P										0.586**	0.578**	-0.089	0.528**	0.348*
X11	G											**0.694****	**-0.302***	**0.458****	**0.363****
	P											0.585**	-0.253	0.373**	0.144
X12	G												**-0.451****	**0.502****	**0.585****
	P												-0.364**	0.518**	0.445**
X13	G													**0.238**	**0.142**
	P													0.231	0.116
X14	G														**0.910****
	P														0.710**

Figures in bold represent direct effect; * Significance at 0.01 probability level; **Significance at 0.05 probability level; X1 = root length; X2 = shoot length; X3 = root volume; 4 = root dry matter; X5 = shoot dry matter; X6 = root/shoot ratio; X7 = days to flowering; X8 = days to maturity; X9 = plant height at harvest; X10 = no. of primary branches; X11 = no. of secondary branches; X12 = no. of pods/plant; X13 = 100-seed weight; X14 = grain yield/plant; X15 = grain yield/plot.

Table 4 Path coefficient analysis of grain yield per plant in chickpea.

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	"r" values
X1	**-0.1008**	0.0010	-0.0038	-0.0193	0.4977	-0.0714	0.0243	0.0100	-0.0077	0.0819	-0.1200	0.0950	-0.0077	0.379**
X2	-0.0028	**0.0371**	-0.0070	0.5165	-0.1726	-0.0526	-0.0358	-0.0078	0.0235	-0.0169	0.0481	-0.0171	0.0013	0.314*
X3	-0.0286	0.0193	**-0.0134**	0.3825	-0.1837	-0.0181	-0.0165	-0.0037	0.0044	-0.0074	-0.0498	0.0299	0.0226	0.118
X4	0.0018	0.0176	-0.0047	**1.0907**	-0.8403	-0.0464	0.0123	-0.0040	0.0198	-0.0539	-0.0023	-0.0560	0.0198	0.131
X5	0.0394	0.0051	-0.0020	0.7261	**-1.2623**	0.0698	-0.0080	-0.0014	-0.0140	-0.1337	0.0743	-0.1357	0.0128	-0.630**
X6	-0.0490	0.0132	-0.0016	0.3425	0.5951	**-0.1480**	0.0336	-0.0051	0.0305	0.1287	-0.1085	0.1231	-0.0150	0.939**
X7	-0.0259	-0.0141	0.0023	0.1417	0.1176	-0.0525	**0.0945**	0.0132	-0.0659	0.1114	-0.0829	0.1077	0.0068	0.340*
X8	-0.0107	-0.0102	0.0017	-0.1549	0.0606	0.0266	0.0441	**0.0284**	-0.0287	-0.0248	-0.0094	0.0056	-0.0148	-0.086
X9	0.0059	-0.0007	0.0005	0.0571	0.2279	-0.0313	0.0091	0.0059	**0.0232**	0.0096	0.0461	0.0483	-0.0709	0.331*
X10	-0.0396	-0.0030	0.0005	-0.2816	0.8083	-0.0912	0.0504	-0.0034	-0.0505	**0.2088**	-0.1817	0.1800	0.0151	0.612**
X11	-0.0557	-0.0082	-0.0031	0.0113	0.4321	-0.0740	0.0361	0.0012	-0.0505	0.1748	**-0.2171**	0.1962	0.0151	0.458**
X12	-0.0339	-0.0022	-0.0014	-0.2161	0.6057	-0.0644	0.0360	0.0006	-0.0754	0.1329	-0.1507	**0.2828**	-0.0121	0.502**
X13	0.0046	0.0052	-0.0004	0.1289	0.1054	-0.0270	-0.0372	-0.0049	0.16715	-0.0321	0.0656	-0.1276	**0.0099**	0.238

Residual effect = 0.1065. Figures in bold represent direct effect; * Significance at 0.01 probability level; **Significance at 0.05 probability level; X1 = root length; X2 = shoot length; X3 = root volume; 4 = root dry matter; X5 = shoot dry matter; X6 = root/shoot ratio; X7 = days to flowering; X8 = days to maturity; X9 = plant height at harvest; X10 = no. of primary branches; X11 = no. of secondary branches; X12 = no. of pods/plant; X13 = 100-seed weight; X14 = grain yield/plant; X15 = grain yield/plot.

DISCUSSION

A moderate to wide range of variation was observed for all the above traits mentioned. Phenotypic and genotypic coefficient of variation reveals the extent of variability present for the different characters in the breeding material. High GCV and PCV were observed for root volume, root dry weight, shoot dry weight and root to shoot dry weight ratio. Moderate GCV and PCV were observed for root length while it was low for shoot length (Latha 1997; Gireesha *et al.* 1999; Mane 2001). The heritability estimates separates the environmental influence from the total variability and indicates accuracy with which a genotype can be identified by the phenotypic performances, thus making the selection more effective. Heritability was high for the entire root related traits i.e. root length, shoot length, root volume, root dry weight, shoot dry weight and root to shoot ratio (Gireesha *et al.* 1999; Mane 2001). In contrast to this the heritability estimates in broad sense for root traits were reported to be low to intermediate by Painawadee *et al.* (2009). Heritability values when used in conjunction with GAM gives better response in selection program. Highest GAM was obtained for root volume followed by shoot dry weight, root dry weight and root to shoot ratio. But moderate GAM was observed for root length and low for shoot length. Kashiwagi *et al.* (2005) studied the genetic variability for different root parameters in the minicore germplasm collection of chick-pea at ICRISAT. They observed largest genetic variability for root length density followed by ratio of plant dry weight to root length density. But they did not study the association of these root traits with seed yield.

Root length manifested significant positive association with root volume and root to shoot dry weight ratio but it showed negative association with shoot dry weight. This is expected because as the root length increases it will result in increase of root volume and root to shoot ratio also. Similarly, root volume was found to be significantly associated with root dry weight. Under conditions of deficit shoot growth slows down markedly while maximum root length increases indicating major changes in partitioning which results in negative association between root length and shoot dry weight (Price *et al.* 2002). Correlation of root volume with root length and shoot length was positive and significant. Zuno-Altoveros *et al.* (1990) and Painawadee *et al.*

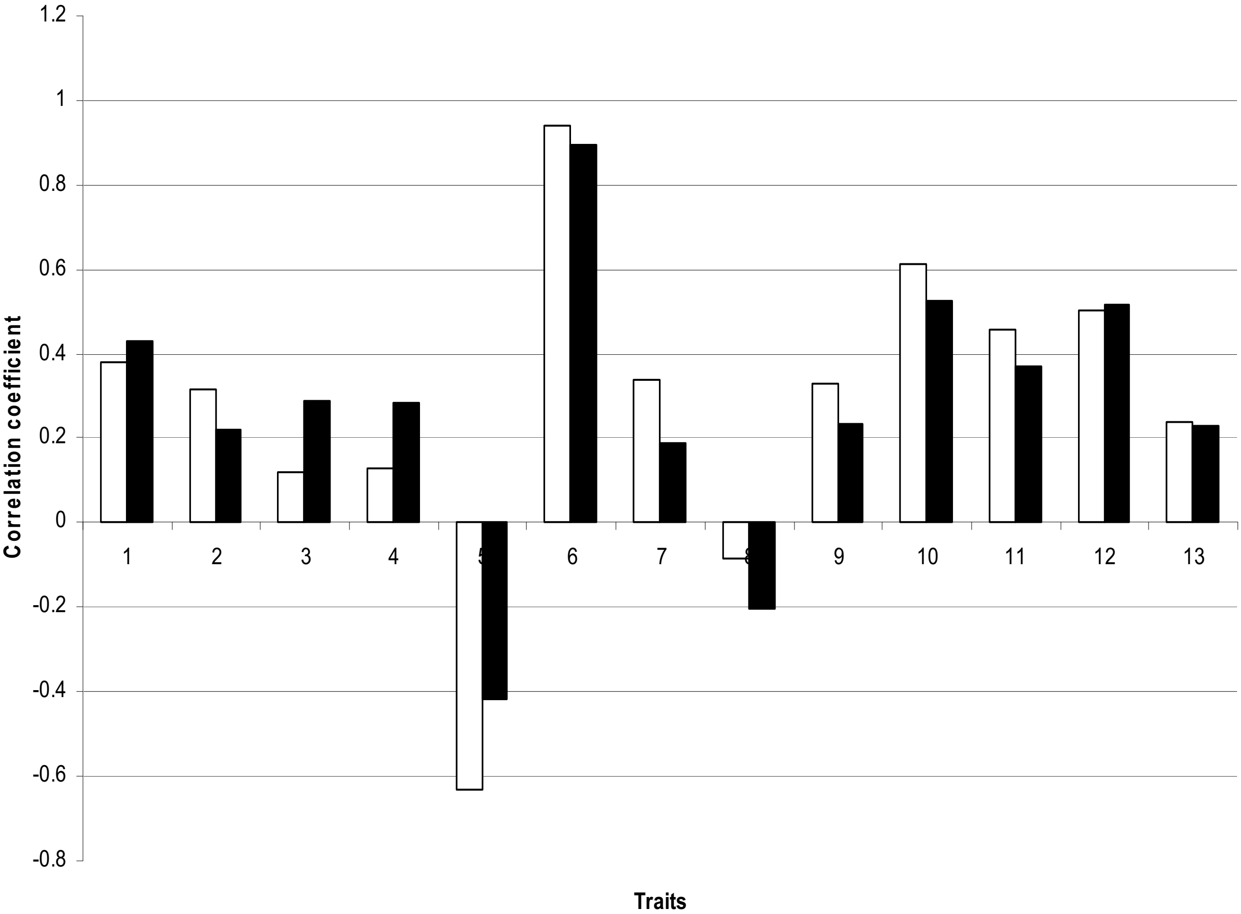

Fig. 3 Genotypic and phenotypic correlation co-efficients of various traits with grain yield per plant. 1 = root length, 2 = shoot length, 3 = root volume, 4 = root dry weight, 5 = shoot dry weight, 6 = root to shoot ratio, 7 = days to 50% flowering, 8 = days to maturity, 9 = plant height at harvest, 10 = no. of primary branches, 11 = no. of secondary branches, 12 = pods per plant, 13 = 100-seed weight. Values represent the correlation values for different traits with grain yield per plant. Bars on positive side of Y axis represent positive correlation and those on negative side negative correlation. White bars = genotypic correlation co-efficient; black bars = phenotypic correlation co-efficient.

(2009a, 2009b) also reported positive association among the root characters. Root dry weight showed significant positive correlation with shoot dry weight and root to shoot dry weight ratio but shoot dry weight exhibited significant negative association with root to shoot dry weight ratio. Negative association is obvious because as the shoot dry weight will increase it will result in a decrease of root to shoot dry weight ratio.

Gahoonia *et al.* (2007) did similar study where he studied the variation in root morphological traits in both *desi* and *kabuli* types of chickpea and their association with the uptake of nutrients. Correlation between root length with nutrient uptake was non significant while significant association was found with amount of root hairs the genotype has. The correlation studies between different root traits and other parameters were estimated at seedling stage of chickpea by Ali *et al*. (2010). Positive and significant genotypic and phenotypic correlations were found for different parameters like seedling length, root length, root/shoot ratio, seedling biomass, leaf length, leaf width and leaf area. Serraj *et al*. (2004) conducted investigations on a RIL population of chickpea derived from the cross between lines contrasting for root length to identify QTL for desirable root traits and to investigate the relationship between root traits, plant growth and seed yield under terminal drought stress. However, they reported no general correlation between seed yield and root size.

Root length was found to be significantly associated grain yield per plant both at genotypic and phenotypic levels. Results were similar to those of Jordan and Miller (1983); Sarkar *et al.* (2005) and Parameshwarappa *et al.* (2010). Entries like 'ICC 12449' (3.802 g/plant), 'ICC 6126' (3.684 g/plant), 'ICC 5743' (3.671 g/plant) and 'ICC 10819' (3.378 g/plant) having deeper roots were found to have comparatively higher yield in the present study. Shoot length showed significant positive correlation with grain yield only at genotypic level while root volume and root dry weight showed significant relationship at phenotypic level only. Root biomass along with root depth was recognized as the main drought avoidance trait to improve seed yield by Ludlow and Muchow (1990); Subbarao (1995) and Turner *et al.* (2001) and Parameshwarappa *et al*. (2010). Shoot dry weight showed significant negative correlation with grain yield/plant while root to shoot dry weight ratio showed very high positive correlation values with grain yield. A high ratio of dry root weight to shoot weight was also found to maintain higher plant water potentials and hence has a positive effect on yield under stress (Mambani and Lal, 1983). 'ICC 5688' (3.647 g/plant), 'ICC 6074' (3.571 g/plant), 'ICC 10391' (4.078 g/plant), 'ICC 6126' (3.684 g/plant), 'Annigeri-1' (3.266 g/plant), 'ICC 10819' (3.378 g/plant), 'ICC 12449' (3.802 g/plant), 'ICCV 6104' (3.8 g/plant), 'BGD 134' (3.465 g/plant), 'ICCV 6106' (3.416 g/plant) were some of the entries with high root to shoot ratio and also yield potential.

In order to obtain the developmental relation, the cause and effect relationship between yield *per se* and remaining significant characters at genotypic level, path coefficient analysis was carried out. Among the characters studied at genotypic level, influence of root length on grain yield was negative. However, its positive correlation with grain yield might be because of its high positive indirect effect through shoot dry weight. Shoot length had positive but negligible direct effect on yield. Its indirect effect through root dry weight was very high and this was the main reason for its significant association with grain yield as indirect effect through all other traits was very less in magnitude. The direct effect of shoot dry weight on grain yield was very high and negative which resulted in moderately high negative correlation with grain yield. But its indirect effect through root dry weight was also high and positive which made the correlation between the two traits to be less negative. Root to shoot dry weight ratio exhibited very high positive correlation with grain yield but its direct effect on yield was low and negative. The high positive correlation can be attributed to high positive indirect effect through root and shoot dry weight. Aslam and Tahir (2003) reported a high positive indirect effect of root to shoot dry weight ratio on grain yield through leaf venation in wheat. Ping *et al*. (2003) showed that maximum basal root thickness, maximum root length and root number have the greatest direct effect on drought resistance index in rice. Further, they also reported a high direct effect on drought resistance index through root to shoot dry weight unlike the present study which shows a low positive direct effect on yield. Saleem *et al*. (2004) observed that root to shoot dry weight ratio had a negative direct effect and a maximum positive indirect effect through 1000-grain weight followed by spike length and tillers per plant on grain yield in wheat. Root density had a positive direct effect on grain yield. Moderate indirect positive effects through number of primary branches and number of secondary branches also resulted in positive association.

CONCLUSION

From the results obtained in our work, it can be concluded that entries with high root length and root to shoot ratio usually give better performance under stress conditions due to drought avoidance nature. Chickpea entries with long roots and high root to shoot ratio showing high yield potential under rainfed condition like ‘ICC 12449’, ‘ICC 6126’, ‘ICC 5743’, ‘ICC 5688’, ‘ICC 6074’, ‘ICC 10391’, ‘Annigeri-1’, ‘ICC 10819’, ‘ICCV 6104’, ‘BGD 134’, and ‘ICCV 6106’ could be utilized in further breeding programmes.

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