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Implications of contrast in root traits on seed yield of chickpea under drought situations

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ABSTRACT

Twelve contrasting root- trait genotypes of chickpea that were identified from the entire mini-core collection plus several popular genotypes (total n= 223), were studied for their consistency in root characteristics and the contribution of these characteristics to seed yield under drought situation. The root growth was assessed using tall PVC cylinders along with the seed yield and shoot biomass under non-irrigated field conditions. Most of the genotypes showed consistent root growth across the seasons except for a minor genotype by season interaction involving only two genotypes. In the field experiment, significant variation among genotypes was found for seed yield under terminal drought stress. The large and small root genotypes were further grouped into early and late group of genotypes to assess the impact of root system variation on seed yield. Among the six early maturing genotypes, a single large root genotype (ICC 4958) showed significantly higher seed yield than the rest of the five genotypes which had small and shallow root systems. Similarly, four prolific and deep rooting genotypes of the late maturity group produced significantly higher yields than the two small and shallow rooting genotypes. The root-size conferred yield advantage was through improved harvest index alone in early maturity genotypes, whereas it was through both harvest index and shoot biomass in the late maturity genotypes. The results demonstrate that the root length density and rooting depth contribute to the seed yield of chickpea under the terminal drought, with the contribution becoming more in the case of late maturing genotypes.

Key words: Chickpea, Maturity, Root traits, Terminal drought, Yield

As most of the chickpea (*Cicer arietinum* L.) crop is cultivated under rainfed environments (4), terminal drought is one of the serious constraints that limits the productivity. The terminal drought is typical of the post-rainy season in the semi-arid tropical regions where the crop grows and matures on a progressively depleting soil moisture profile. In the last decade, major breeding efforts were made to shorten the maturity of chickpea to cope with the terminal drought environment. Adoption of this drought escape breeding strategy has seen several successful super-early varieties, *e.g.*, ICCV 2, being released and spread to the farmers' fields in the peninsular India (5). Yield stability was successfully achieved by such super-early maturing varieties, however, their seed yield was relatively low compared to early and medium maturity varieties mainly due to a shortened total photosynthetic period. It is, therefore, important to identify traits that confer improved drought tolerance and then to develop a trait-based breeding strategy.

Root biomass as well as rooting depth was recognized as the main drought avoidance trait to improve seed yield (6, 9, 10). Although they are recognized as highly useful traits, the breeding programme to improve the root traits has not progressed very much. This is mainly due to inadequacy in the sources of tolerance and difficulties in quantifying these traits effectively under field conditions. Extensive research targeted to identify sources of deep and large root system has resulted in the identification of the chickpea variety ICC 4958 which have relatively early maturity (8). Until recently, most of the chickpea root studies were still based on a narrow genetic base involving only one genotype, *i.e.*, ICC 4958. Recently, genetic variability on root traits has been investigated in chickpea mini-core germplasm collection (11) that broadly represents the whole range of variation in the entire chickpea germplasm collection at ICRISAT. This has been recognized as a valuable germplasm pool to explore for more chickpea materials with a broader contrast in root system.

The major objectives of this study were to evaluate the consistency and stability of root characteristics of contrasting chickpea genotypes across seasons, and to evaluate the relevance of root traits to chickpea seed yield under terminal drought environment.

MATERIALS AND METHODS

The experiments in cylinder systems and field were conducted at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru in 2002-2003. Twelve contrasting chickpea genotypes were selected for both the root biomass and rooting depth from the entire mini-core germplasm collection (211 accessions), 12 popular cultivars (Annigeri, ICC 4958, Chafa, ICCV 2, JG 62, JG 74, ICCC 42, Phule G 81-1-1, K 850, K 1189, KAK 2, and ICC 898) as references and 10 accessions of wild annual species (ICC 17116 of *C. yamashitae*, ICC 17123 and ICC 17124 of *C. reticulatum*, ICC 17156 of *C. bijugam*, ICC 17200 and ICC 17210 of *C. pinnatifidum*, ICC 17241 of *C. chorassanicum*, ICC 17148 and ICC 17180 of *C. judaicum*, and ICC 17162 of *C. cuneatum*) in the first cylinder experiment started on 23 January in 2002 (first season). The selected 12 genotypes, seven with extremely small and shallow root systems (ICC 9137, ICC 1882, ICC 9402, ICC 12654, ICC 1230, ICC 7308 and ICC 283) and five with extremely prolific and deep root systems (ICC 15518, ICC 7571, ICC 10755, ICC4958 and ICC 8261) were further evaluated for the root traits again in the second cylinder experiment started on 15 November 2002 (second season).

In the cylinder experiments meant for root assessment, the chickpea plants were grown on a 18-cm diameter, 120-cm tall PVC cylinders in a randomized block design with two replications in the first season, and four replications in the second season. The cylinders were placed in pits to avoid differential heating due to direct solar radiation. The cylinders were filled with an equi-mixture (w/w) of Vertisol and sand, with initial soil water content equivalent to 70% of field capacity. Four seeds of each genotype were sown in the soil-sand mixture. Immediately after sowing, all cylinders were supplied with a *Rhizobium* inoculum (strain IC 59) as a water suspension. The top 15 cm of the soil-sand mixture was mixed with di-ammonium phosphate at the rate of 0.07 g kg^{-1}. The plants were irrigated with 150-ml of water thrice thereafter on alternate days for uniform germination. The plants were thinned to two individuals per cylinder seven days after sowing. No further irrigation was given after thinning. All plants were protected from rainfall by mobile rainout shelters. The shoots were harvested at 35 days after sowing (DAS) in both seasons. Then, the cylinders were placed horizontally and soil-sand mixture from both sides of the cylinders was removed using water. When approximately three quarter of the filled soil-sand mixture was washed away, the cylinder was erected gently on a fine wire mesh so that the whole undamaged root system can be easily slipped down on the wire mesh. After removing the debris from the roots, they were stretched to measure the rooting depth. The root length was measured using an image analysis system (WinRhizo, Regent Instruments INC., Canada). The root length density was calculated by dividing the total root length by the cylinder volume. The root and shoot dry weights were recorded after drying in a hot air oven at 80°C for 72 hours. The root length density is considered as the potential unit for absorption of water from soil, and the root dry weight as root growth in the biomass accumulation (1).

The field experiment was sown on 31 October 2002 in a vertisol field (fine montmorillonitic isohyperthermic typic pallustert). Before sowing, 100 kg ha^{-1} of di-ammonium phosphate was applied. The individual plot size was 0.75 m x 4.0 m with 33.3 plants m^{-2} on a broad-bed furrow in a randomized block design with three replications. Immediately after sowing, *Rhizobium* (strain IC 59) was applied and followed by 20-mm sprinkler irrigation for uniform seedling emergence. Further, the plants were cultivated under rainfed conditions. The phenology was recorded, and the plants were harvested from an area of 2 rows (0.75 m) x 3.3 m at the maturity to measure the shoot biomass and seed yield. The shoots were dried in a hot air dryer at 80°C for three days and the dry weights were recorded. The shoots were threshed and the extracted seeds were weighed for recording the seed yield.

RESULTS AND DISCUSSION

During the cylinder culture experiment in the first season, maximum air temperature was relatively higher than in the second season (Fig. 1). Chickpea plants, therefore, grown in the first season were subjected to relatively higher temperature regimes. In the field experiment, rainfall ceased in October 2002, and except for a 0.4 mm rain on 18 February 2003, there was no other rainfall incidence during the growing period (data not shown). Thus the chickpea would have experienced severe terminal drought, especially during later growth stages.

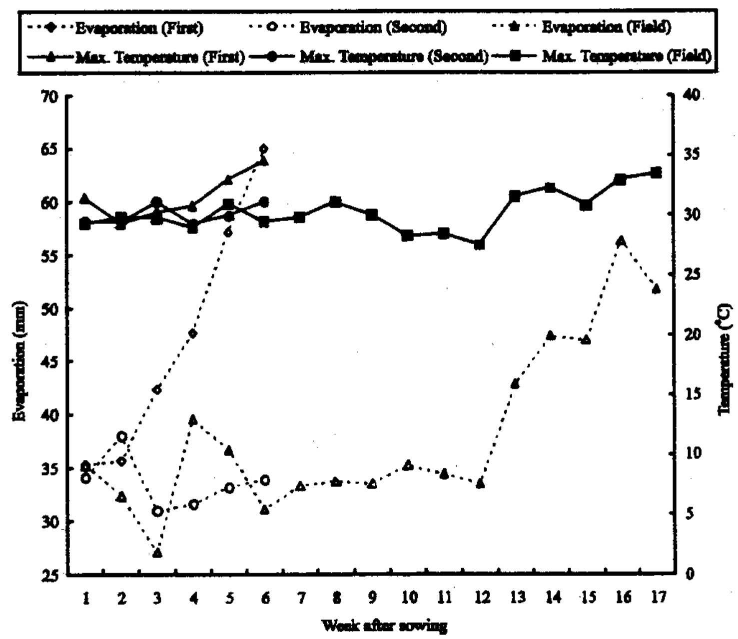

Fig 1. Climatic conditions during the crop growing period in 2002-2003. First and second indicate the first and second cylinder trials, respectively

In the cylinder experiments, there were significant differences on root dry weight (RDW), root length density (RLD) and rooting depth (RDp) among the 12 chickpea genotypes at 35 DAS (Table 1). A significant genotype by season (G x S) interaction was observed for RDW and RLD (Table 1) and the G x S interaction was not strong as it was only one-third of the genetic variation. Such genotype by environment (G x E) interaction was also observed for root traits in some other crops, *e.g.*, rice (2). Most of the genotypes exhibited consistency in root growth across seasons, but for genotypes ICC 9137 in RDW and ICC 10755 in both RLD and RDp (Table 2). As the G x S interaction was limited to two genotypes, the pooled means of RDW, RLD and RDp across first and second seasons (Data not shown) was used to

Table 1. ANOVA of root traits among 12 chickpea genotypes in two different seasons in cylinder systems

Source of variation		RDW		RLD		RDp	
	d.f.	m.s	F-predicted	m.s	F-predicted	m.s	F-predicted
Season(S)	1	0.029	0.014	0.004	0.132	545.5	0.206
Genotype(G)	11	0.043	<0.001	0.014	<0.001	1351.3	<0.001
(G) x (S)	11	0.015	0.002	0.004	0.011	469.6	0.207
Residual	39	0.004		0.002		330.1	

RDW = root dry weight (g plant^{-1}), RLD = root length density (cm cm^{-3}), RDp = rooting depth (cm)

Table 2. Mean of root traits among 12 chickpea genotypes in two different seasons in cylinder systems

Root size group/Genotype	RDW		RLD		RDp	
	First	Second	First	Second	First	Second
Small Root Group						
ICC 9137	0.156	0.322	0.122	0.199	81.0	106.8
ICC 1882	0.198	0.255	0.126	0.194	72.5	93.8
ICC 9402	0.237	0.171	0.156	0.134	81.0	93.8
ICC 12654	0.243	0.249	0.162	0.184	70.0	105.5
ICC 7308	0.266	0.194	0.169	0.151	81.0	91.5
ICC 283	0.278	0.216	0.168	0.158	92.5	92.8
Large Root Group						
ICC 15518	0.394	0.424	0.281	0.241	125.0	116.0
ICC 7571	0.422	0.379	0.275	0.259	124.0	129.5
ICC 10755	0.428	0.265	0.272	0.184	131.0	103.8
ICC 4958	0.500	0.308	0.319	0.235	120.0	116.0
ICC 8261	0.541	0.377	0.314	0.233	131.0	116.0

First = first season in 2002, Second = second season in 2002
RDW = root dry weight (g plant^{-1}), RLD = root length density (cm cm^{-3}), RDp = rooting depth (cm)

classify all the 12 genotypes into two groups (small and shallow roots and large and deep roots) (Table 2).

There were significant differences in seed yield among the 12 genotypes ($p < 0.001$, data not shown). The stored soil moisture and the weather at Patancheru have been shown to support short crop growth duration and the late duration chickpea genotypes have been shown not to be adapted to this region as the reproductive stage of crop growth occurs during severe water deficit as well as high temperatures (7). The influence of root system variation on seed yield under drought can be expected to vary depending on the duration of the genotype. In the previous years, it indeed has been noticed that the genotypes that mature approximately beyond 100 DAS yield generally poor (3) and the extent depending upon the delay in maturity. Therefore, the 12 genotypes were categorized into two groups with the early maturity group containing genotypes that matured <100 DAS (ICC 4958, ICC 1882, ICC 12654, ICC 1230, ICC 7308 and ICC 283) and the late maturity group that matured after 100 DAS (ICC 15518, ICC 7571, ICC 10755, ICC 8261, ICC 9137 and ICC 9402). In the early maturity group, the single constituent genotype

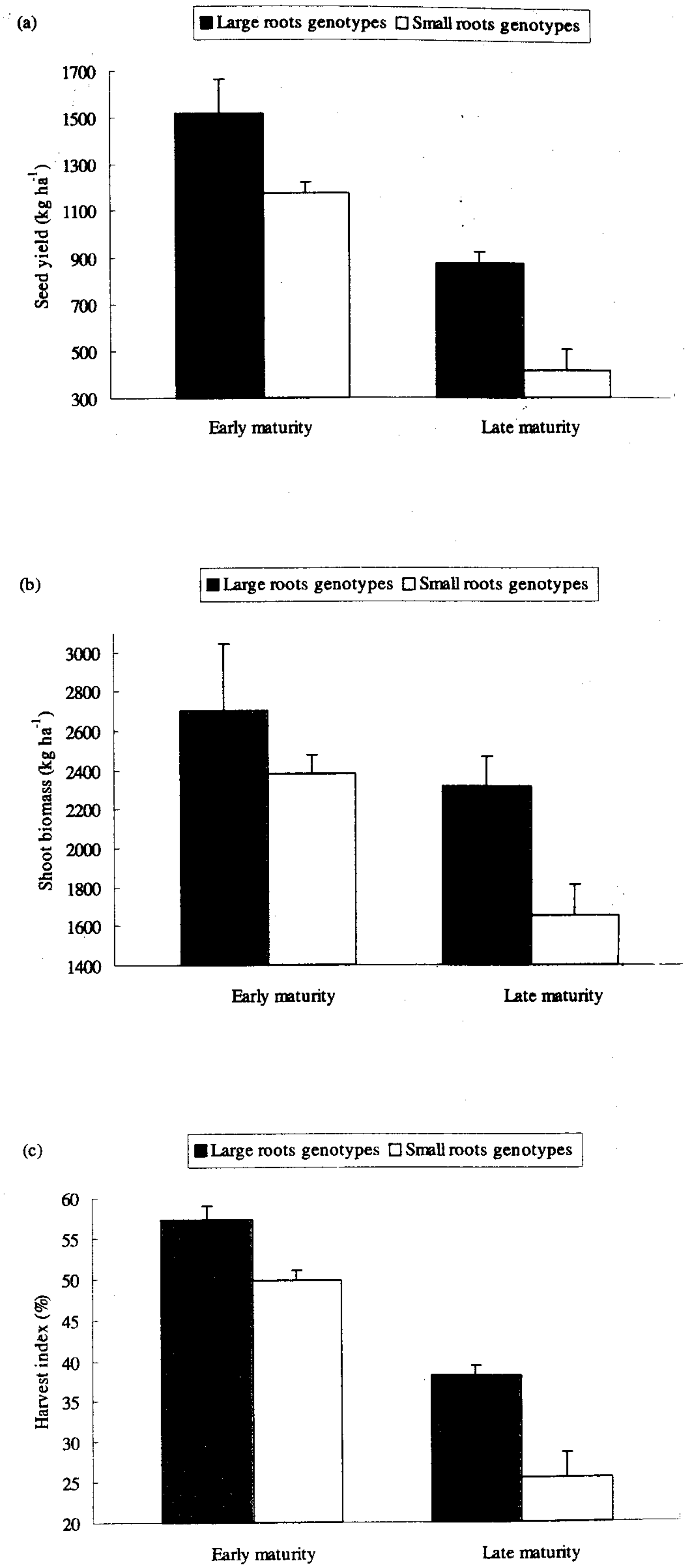

Fig 2. Differences in (a) seed yield, (b) shoot biomass and (c) harvest index between the different root size groups (large and deep roots verses small and shallow roots) in early and late maturity chickpea genotypes observed in a field experiment grown under residual soil moisture

ICC 4958 that had large and deep root system had significantly yielded higher than that of the genotypes with small and shallow root systems, *i.e.*, ICC 1882, ICC 12654, ICC 1230, ICC 7308 and ICC 283 (Fig 2a). Similar root size-dependant effect could also be seen in the late maturity group. The mean yield of larger and deeper root genotypes ICC 15518, ICC 7571, ICC 10755 and ICC 8261 was significantly larger than that of the mean of smaller and shallower root group genotypes (ICC 9137 and ICC 9402). However, the average mean yields of late duration genotypes was considerably less than that of the early duration group.

In the early maturity group, the differences observed in shoot biomass between the large and small root size groups was not significant (Fig 2b). Whereas the differences observed in harvest index between large and small root groups were significant (Fig 2c). On the other hand, both shoot biomass and harvest index varied significantly between the two root size groups in the late maturity group (Fig 2b and Fig 2c). These interesting results indicate that the mode of contribution of the root traits to seed yield was different between the maturity groups. Analytically, the seed yield is a function of total shoot biomass and harvest index (10). Under terminal drought situations, it can be visualized that the major shoot biomass production is completed before the development of serious soil water deficits in short and medium duration genotypes. Therefore, the advantages of prolific or deep root system are expected to manifest in terms of genotypic variation in partitioning alone. However, in the late duration group of genotypes, both the biomass production and its partitioning are expected to be affected and the larger and deeper root system can bring about larger changes both in total biomass production as well as its partitioning reflecting in seed yields under drought situation (6). These results suggest that incorporating the prolific and deep root system into early maturity would be an effective breeding strategy to improve seed yield under terminal drought situations in short-duration environments similar to that of peninsular India.

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