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Multilocation analysis of yield and yield components of a chickpea mapping population grown under terminal drought

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ABSTRACT

Terminal drought is one the major causes of yield losses in chickpea (*Cicer arietinum* L.) and there is a scope for recovery of major part of this loss through genetic improvement. The progress in breeding for drought tolerance is slow due to the quantitative and temporal variability of available moisture across years and the low genotypic variance in yield under drought. Deep and prolific root system is a high priority trait that can improve drought avoidance in chickpea. Current availability of recombinant inbred lines (RIL) with the known variation for root system combined with DNA markers will be useful to improve our ability to study and manipulate drought avoidance. The genetic variation for seed yield in a set of 257 RILs derived from a cross between a drought-tolerant breeding line with a large root system (ICC 4958) and an agronomically preferred variety grown in peninsular India (Annigeri) and the parents were studied during 2000-2003 at Patancheru, Guntur and Kanpur to assess the suitability of this RIL population for mapping of QTL contributing to drought avoidance. There was a large G by E variation for both seed yield and shoot biomass, indicative of the need for selection for each of these locations. But for harvest index there were RILs with consistent performance across locations. The heritability index range of 0.090 -0.234 for seed yield, 0.040-0.271 for shoot biomass and 0.052 -0.501 for harvest index was relatively low and these values were the highest at Patancheru. At Guntur, the yield limitations were mainly due to low biomass production as a consequence of late sowing. At Patancheru, there was high variability for yield and shoot biomass of RILs, as well as for the growth duration. Both shoot biomass and partitioning were positively related to yield. However at Kanpur, where all the RILs matured at the same time, there were no differences in yield among the RILs and shoot biomass was not a limitation. Partitioning, with a positive association with yield was a limitation. The RILs were grouped into five groups with distinct differences at the low environmental yield (intercept) on the basis of stability analysis. The parent ICC 4958 was the most stable one with the highest yield at lowest environment. There were 47 other RILs whose performance was similar to that of ICC 4958.

Key words: Chickpea, Harvest index, Partitioning, Recombinant inbred lines, Terminal drought

Chickpea is one of the most important pulse crops globally, with over 73% of the production coming from South-East Asia (4). Major chickpea production worldwide is predominantly under rainfed conditions, grown on residual, progressively declining soil moisture. Terminal drought is a primary constraint to chickpea productivity. Thus, there is a clear need to improve tolerance to constraints, with particular emphasis on drought stress. On this basis, there appears to be better opportunities for improving yield stability under stress rather than increasing the yield potential. It is critical that both agronomic and genetic management strategies focus on maximum extraction of available soil moisture and its efficient use in crop establishment, growth, and seed yield. Chickpea improvement with early-maturity to escape terminal drought and heat stress can be one option (7), although drought escape carries the penalty of decreasing potential yield through inability to utilize the extended growing periods, when available. Therefore, for achieving high and stable yields under drought, it is necessary to develop drought tolerant/avoiding varieties (8).

Breeding for enhanced yield stability and/or potential under drought stress has been quite successful in some crops (34). The progress in breeding for drought tolerance is slow due to the quantitative and temporal variability of available moisture across years, the low genotypic variance in yield under these conditions and inherent methodological difficulties in evaluating component traits together with the highly complex genetic basis of this character (20). The availability of RILs combined with DNA markers in chickpea has the potential to improve our ability to study and manipulate drought tolerance. In particular, introgression of simple component traits that contribute to yield under specific target drought environments appears to be within reach (14).

Several physiological, morphological and phenological traits may play a significant role in crop adaptation to drought stress during soil drying (16). Root traits play a major role in drought tolerance under terminal drought environments. In terms of root architecture, both more prolific root systems extracting more of the water in upper soil layers and longer root systems extracting soil moisture from deeper soil layers are important for maintaining yield under terminal drought (20). Association of deep root morphology and root thickness with increased water extraction during progressive water stress (5) and a high ratio of deep root weight to shoot weight with maintenance of good plant water potential and positive effect on yield under stress (9) had been documented in upland rice. Contribution of root traits to drought tolerance particularly in chickpea is also well established (17,19).

Efforts made at ICRISAT and ICARDA during the past decade, to identify chickpea germplasm accessions that possess large and deep root systems and to incorporate these traits into a well-adapted cultivars, have resulted in identification of a germplasm accession ICC 4958 as one of the most drought-resistant (8) breeding line (13) and subsequent development of drought-tolerant lines by improving the root system (17). However, difficulties faced on the concurrent selection for root traits and yield performance has led to a strong justification for the application of marker-assisted selection (12). Similar efforts for development of QTL markers for root traits aimed at molecular breeding of drought tolerance in rice (2) has proved that rapid success is possible in this direction. Large variation on root traits was identified among the recombinant inbred lines derived from ICC 4958 and Annigeri (15).

The objective of this study was to quantify the genetic variation for seed yield amongst a set of RILs and their parents, specifically bred for variation in root biomass (15) across contrasting locations and to study the relationship between the yield and shoot biomass at each of these locations. These results were expected to indicate the suitability of the RIL population for mapping of QTL contributing to seed yield through deep and prolific roots.

MATERIALS AND METHODS

A recombinant inbred line (RIL) population of 257 individuals was developed from a cross between ICC 4958 and Annigeri, for mapping QTLs for yield and yield components. The germplasm accession ICC 4958 was identified as one of the most drought-resistant entries out of more than 1500 diverse germplasm accessions screened for drought resistance under field conditions between 1978 and 1983 at ICRISAT, and subsequently at ICARDA. This accession had 30% greater root length density and mass at early stages of crop growth than Annigeri. The larger root system was believed to confer the increased drought tolerance in ICC 4958. Annigeri is a drought-tolerant genotype well adapted to the peninsular Indian region. Field evaluation of this RIL population (F_8 in 2000-01, F_9 in 2001-02 and F_{10} in 2002-03) and the parental genotypes was conducted during the post-rainy seasons of 2000-01 and 2001-02 at ICRISAT Patancheru, 2001-02 at Regional Agricultural Research Station, Guntur and 2002-03 at Indian Institute of Pulses Research, Kanpur.

At ICRISAT, Patancheru (17° 30'N; 78° 16' E; altitude 549 m), experiments were conducted on a Vertisol (fine montmorillonitic isohyperthermic typic pallustert). The soil depth of the fields used in the two seasons was ≥ 1.2 m and these soils retained about 190 mm of plant available water in the 120-cm (maximum rooting depth) soil profile. The field used for the 2001-02 post-rainy season was solarized using polythene mulch during the preceding summer to eradicate wilt causing *Fusarium*, as chickpea was often grown in this field. The field chosen for 2000-01 was not solarized as chickpea was grown in this field once in 4-years.

The field was prepared into 0.6 m ridges and furrows for the 2000-01 and as a flat seed bed for the 2001-02 experiments. Surface application and incorporation of 18 kg N/ha and 20 kg P/ha as diammonium phosphate was carried out in both experiments. The plot size for the 2000-01 experiment was 4 m x 1 row and the 2001-02 experiment was 4 m x 5 rows. It was an 11 x 24 alpha-lattice design (264 genotypes) with two replications during 2000-01 and 7 x 40 alpha-lattice (280 genotypes) with three replications during 2001-02. In addition to the 257 RILs and their two parents, the experiments had five other varieties during the 2000-01, and 21 during the 2001-02 season. Seeds were treated with 0.5% Benlate® (E.I. DuPont India Ltd., Gurgaon, India) + Thiram® (Sudhama Chemicals Pvt. Ltd., Gujarat, India) mixture in both the seasons. During the 2000-01 season, the seeds were drilled at 5-cm depth in rows 60 cm apart using a 4-cone planter on 17 Oct 2000 (as the first opportunity after the rains). About 45 seeds were used for each 4-m row and at 15 days after sowing the plants were thinned maintaining a plant-to-plant spacing of 10 cm. During 2001-2002, the seeds were hand sown manually at a depth of 2 to 3 cm with a 15 cm distance between the plants within a row and 20 cm between rows on 2 Nov 2001 in a dry seed bed. During both the seasons, the fields were inoculated with *Rhizobium* strain IC 59 using liquid inoculation method (1). A 20-mm irrigation was applied the next day to ensure complete emergence. Two seeds per hill were sown which was thinned to one at 12 days after sowing. Intensive protection against pod borer (*Helicoverpa armigera*) was provided and the plots were kept weed free by manual weeding.

At RARS, Guntur (16^0 18'N; 18^0 29' E; altitude 35.1 m), experiments were conducted on a Vertisol as that of ICRISAT center. The soil depth of the field was ≥:1.2 m.

Field was prepared into a flat seed bed. Surface application and incorporation of 18 kg N/ha and 20 kg P/ha as diammonium phosphate was carried out. The plot size was 4 m x 3 row in a 7 x 40 alpha-lattice (280 genotypes) with three replications. The seed was drilled at 5-cm depth with rows 30 cm apart, using a bullock drawn plough on 16 Dec., 2001. Continuous seeding was done on each 3-m row and at 12 days after sowing the plants were thinned maintaining a plant-to-plant spacing of 10 cm. A 30-mm irrigation through perfo was applied the next day to ensure complete emergence. Seed treatment with fungicide, plant protection measures, and weeding was the same as practiced at Patancheru.

At IIPR, Kanpur (26^0 27' N; 80^0 14' E; altitude 152.4 m), the experiments were conducted on an inceptisol. The soil depth of the field was >2.0 m. Field was prepared into a flat seed bed after presowing irrigation. Surface application and incorporation of 18 kg N/ha and 20 kg P/ha as di-ammonium phosphate was carried out. The plot size was 2 m x 4 rows in a 13 x 20 alpha-lattice (260 genotypes) with three replications. Two seeds per hill at 10 cm distance were drilled at 5-cm depth, with rows 30 cm apart manually on 8 Nov., 2002. At 12 days after sowing, the plants were thinned maintaining a plant-to-plant spacing of 10 cm. Seed treatment with fungicide, plant protection measures, and weeding was the same as practiced at Patancheru.

Through regular observations, the mean date at which more than 50% of the plants reached flowering were recorded as 50% flowering time and when 80% of the pods dried, this was recorded as the physiological maturity for each plot. This observation was not recorded at Guntur.

At physiological maturity, plant aerial parts were harvested from an area of 2.4 m^2 in 2000-01 and 3.45 m^2 in 2001-02 at Patancheru, 2.25 m^2 at Guntur (6 Mar 2002), and 2.4 m^2 at Kanpur in each plot and dried to constant weight in hot air dryers at 45°C, and total shoot dry weights were recorded. Grain weights were recorded after threshing. Harvest index (%) was calculated as 100 x (Seed yield / Total shoot biomass at maturity).

The data from individual experiments were analyzed using linear additive mixed effects model,

$$Y_{ijk} = \mu + r_i + b_{ij} + g_k + e_{ijk}$$

Where Y_{ijk} is the observation recorded on genotype k in incomplete block j of replicate i, μ is the general mean, r_i is the effect of replicate I, b is the effect of block j within replicate I, g_k is the effect of genotype k, and e_{ijk} is the effect of the plot. The general mean μ and replicate effect r_i were considered as fixed effects. The block effect b_{ij}, the RIL effect g_k, and the plot effect e_{ijk}, were assumed as random effects each with mean zero and constant variances $\sigma^2_{\hat{b}}$, $\sigma^2_{\hat{g}}$ and $\sigma^2_{\hat{e}}$, respectively. Using the above model, the statistical procedure of residual maximum likelihood (ReML) was employed to obtain the unbiased estimates of the variance components $\sigma^2_{\hat{b}}$, $\sigma^2_{\hat{g}}$ and $\sigma^2_{\hat{e}}$, and the best linear unbiased predictions (BLUPs) of the performance of the 257 RILs. Heritability was estimated as $h^2 = \sigma^2_{\hat{g}}/(\sigma^2_{\hat{g}} + \sigma^2_{\hat{e}})$. The significance of genetic variability among RILs was assessed from the standard error of the estimate of genetic variance $\sigma^2_{\hat{g}}$, assuming the ratio $\sigma^2_{\hat{g}}$ /SE ($\sigma^2_{\hat{g}}$) to follow normal distribution asymptotically.

The above model was extended for over-location analysis of traits recorded in the four locations, assuming location effect as fixed, with genotype x environment interaction (GEI) effect being a random effect assumed to have a mean of zero and constant variance σ^2_{gE}. The significance of GEI was assessed in a manner similar to that of σ^2_g. The significance of the fixed year effect was assessed using the Wald statistic that asymptotically follows a x^2 distribution and is akin to the F-test in the traditional ANOVA.

The BLUPs of seed yield for RILs obtained for each location were regressed against the location (environmental) means. The intercepts and slopes of RILs (140) and the parents which fitted well ($R^2 = 0.90$) were alone used for clustering the RILs into different classes using Numerical Taxonomy and Multivariate Analysis System (NTSYSPC), version 2.1 from Exeter Software, New York. Similarity/dissimilarity matrix was obtained based on Euclidian distances and thus the entries were grouped on the basis of UPGMA (unweighted pair group method of arithmetic average). Means of all the RILs falling under each group were calculated and the estimates for the lowest yielding environment (Guntur) were also presented for comparison.

RESULTS AND DISCUSSION

This study was carried out to quantify the genetic variation for seed yield amongst the RILs across contrasting environments for assessing the suitability of this RIL population with known root traits for mapping of QTL contributing to seed yield. In the pooled analysis, the location means varied substantially for seed yield, shoot biomass and harvest index (Table 1). The RILs did not vary significantly for seed yield and shoot biomass, but varied for harvest index. However, there was a substantial variation in the location by RIL interaction for all these three characters, and this effect contributed for the largest variance component of the experiments. Thus, the performance of RILs is largely location-specific and the best and worst adapted RILs were not the same across

Table 1. **Components of variance of seed yield, shoot biomass and harvest index at maturity of the 257 RILs and their parents Annigeri and ICC 4958 at three locations during winter 2000-01 and 2002-03**

		Seed yield (kg/ha)		
Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq. probability
Location (L)	1560	3	520	<0.001
Random term	Component	S.E.		
RIL (R)	3562	1903		
(L) x (r)	11894	3621		
Residual	139360	4643		
		Shoot biomass (kg/ha)		
Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq. probability
Location (L)	10730	3	3577	<0.001
Random term	Component	S.E.		
RIL (R)	7505	6014		
(L) x (r)	26632	12268		
Residual	505481	16745		
		Harvest index (%)		
Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq. probability
Location (L)	8142	3	2714	<0.001
Random term	Component	S.E.		
RIL (R)	3.29	0.56		
(L) x (r)	1.91	0.66		
Residual	25.91	0.86		

locations (Table 1). Across environments, large G by E variation has also been observed. The mean shoot biomass was the highest at Kanpur, followed by the two Patancheru experiments, and the lowest at Guntur (Table 2). However, the harvest index was the lowest in Kanpur indicating that this population is not well adapted to this location.

The seed yield of the RILs varied significantly at all locations (Table 2). The yields of Annigeri and ICC 4958 were similar at all the locations, except in highly drought stressed crop of 2001-02 at Patancheru, when the yield of ICC 4958 was greater (1966 kg/ha) than that of Annigeri (1544 kg/ha). The mean and the range of seed yield were low at Guntur as the crop was sown late, and the late sown crops are known to yield low (20). Between the two years at Patancheru, yield of 2000-01 was relatively high. This crop was sown early, and therefore, escaped the drought and heat stress occurring at the later part of the growing season. The yield at Kanpur was the next highest due to longer growing season (137 days) of the crop. Also the differences among RILs in maturity time (Table 3) observed at Patancheru were not apparent at this location. This phenomenon is characteristic of locations at higher latitudes where the winter is relatively cooler and longer. The heritability of seed yield was relatively high (0.234 and 0.139) in the two Patancheru experiments, whereas it was very poor at Guntur (0.090) and Kanpur (0.102) experiments.

The shoot biomass of RILs varied considerably in the two years at Patancheru, whereas it did not vary much at Guntur and Kanpur (Table 2). The mean shoot biomass production at Guntur was the lowest due to very short growing period (81 days for the latest entry to attain maturity), and was highest at Kanpur due to the longest growing period with no variation among RILs (Table 3). However, the variation in growth duration was well exhibited at ICRISAT (Table 3), and consequently the shoot biomass differences. The shoot biomass of Annigeri and ICC 4958 were similar at all locations, except in 2000-01 at Patancheru when the shoot biomass of ICC 4958 was higher (3459 kg/ha) than that of Annigeri (3066 kg/ha). The mean shoot biomass and the range were low at Guntur as the crop was sown late. Between the two years at Patancheru, shoot biomass of 2000-01 was relatively high. This crop was sown early, and therefore, had a longer growing period (Table 3) leading to higher shoot biomass production. The shoot biomass of Kanpur was two times higher than that of Patancheru, and three times than that of Guntur. The per day productivity of shoot biomass in chickpea has been shown to be much higher at locations such as Hisar with higher latitude, while per day productivity of seed remained the same. This results generally in poor harvest indices at the northern Indian locations (10). The heritability of shoot biomass

Table 2. **Trial means, range of best linear unbiased predicted means of RILs (BLUPs) and variance of shoot biomass, seed yield and harvest index of the 257 RILs and their parents Annigeri and ICC 4958 in the field experiments during at Patancheru, Guntur and Kanpur**

Trait	Trial mean	Range of predicted means	σ^2_g (SE)	Heritability (h^2)
Shoot dry matter (kg/ha)				
Patancheru				
2000-01	3407	2613 - 3806	43257 (10739)	0.271
2001-02	3216	2809 - 3667	47513 (13039)	0.167
Guntur (2001-02)	2178	2099 - 2285	11198 (10027)	0.050
Kanpur (2002-03)	6413	6227 - 6588	41371 (38739)	0.040
Seed yield (kg/ha)				
Patancheru				
2000-01	1958	1554 - 2156	13688 (3938)	0.234
2001-02	1706	1507 - 1923	17757 (5746)	0.139
Guntur (2001-02)	1126	102 - 1229	7207 (3221)	0.090
Kanpur (2002-03)	1929	1750 - 2149	18194 (7147)	0.102
Harvest index (%)				
Patancheru				
2000-01	57.5	52.1 - 63.0	4.41 (0.61)	0.501
2001-02	52.0	47.3 - 56.0	7.08 (1.21)	0.301
Guntur (2001-02)	51.5	44.3 - 55.9	7.62 (1.47)	0.240
Kanpur (2002-03)	30.1	28.8 - 32.3	2.00 (1.45)	0.052

was similar to that of the seed yield across locations. The heritabilty of shoot biomass was higher than that of the seed yield at Patancheru and was lower at the other two locations. The heritability values observed at Patancheru can be considered more appropriate as the RIL differences in growing period were well expressed and the crop exposure to terminal drought was effective. Whereas the late sowing-led short growth duration as observed at Guntur and the very less crop exposure to terminal drought along with the high temperature related forced maturity at Kanpur have led to two different and alternative environmental effects leading to severe constraint and no drought constraint for shoot biomass production. The parents of these RILs were not selected to these specific environmental effects and as a consequence led to a severe reduction in the heritability values. For these reasons the values observed at Guntur and Kanpur may not be a reliable indicator for comparison of shoot biomass and seed yield heritability values.

The harvest index of the RILs varied significantly at all individual locations except at Kanpur (Table 2). The harvest index of Annigeri and ICC 4958 were similar at all locations. The mean harvest index and the range were low at Kanpur. The harvest index of chickpea is known to be lower and the shoot biomass production higher at Hisar, where the winter is longer and cooler (10, 11). The cold and occasionally wet weather during December-January is known to delay the reproductive growth and promote vegetative growth, and consequent relatively shorter reproductive duration does not allow adequate pod filling and photosynthate remobilization (18). At Kanpur though the flowering initiation had occurred at 42 DAS (data not shown) in all the RILs and parents, it took another 20 days to reach 50% flowering stage. However, it is likely that the best-adapted genotypes will have a better balance between the vegetative and reproductive growth phases and achieves higher partitioning into seed (12). The heritability of harvest index was relatively high at all locations, except at Kanpur (Table 2).

The vegetative shoot biomass (total shoot biomass - seed yield) exhibited a positive relationship with seed yield at Patancheru, and a negative relationship at Kanpur. At Guntur, the negative relationship was just marginal. In both the experiments at Patancheru, as the range in productivity was large, the vegetative shoot biomass showed its contribution to yield very well. The parent ICC 4958 was one the best in early growth vigor while Annigeri was relatively moderate (13). Therefore. the RILs possessing early growth vigor might have led to better yield performances. However at Kanpur the same early growth vigor led to excessive vegetative growth leading to mutual shading and lodging and the partitioning was adversely affected. Therefore. early growth vigor seems to be advantageous only at locations of lower latitudes whereas a conservative early growth was well suited at higher latitudes.

Harvest index was positively related to seed yield at all locations with varying contributions across locations.

Table 3. **Trial means, range of best linear unbiased predicted means of RILs (BLUPs) and variance of phenology of the 257 RILs and their parents Annigeri and ICC 4958 at Patnacheru and Kanpur**

Trait	Trial mean	Range of predicted means	σ^2_g (SE)	Heritability (h^2)
Days to 50% flowering				
Patancheru				
2000-01	43.5	34.4-48.6	4.01 (0.56)	0.514
2001-02	41.2	38.3-44.0	8.55 (0.78)	0.842
Kanpur (2002-03)	60.8	56.7-63.6	1.978 (0.203)	0.675
Days to maturity				
Patancheru				
2000-01	99.6	95.0-104.1	2.44 (0.36)	0.486
2001-02	84.5	81.2-90.3	5.86 (0.58)	0.713
Kanpur (2002-03)	137	137	-	-

The parents varied for the harvest index contributing to higher seed yield (data not shown) only in the 2001-02 Patancheru experiment when the drought intensity was the highest (15). The highest contribution of harvest index to seed yield has been demonstrated to occur only when the terminal drought conditions were severe (6). Major contribution of harvest index to seed yield was observed at Patancheru during 2001-02. and at Kanpur. This relationship was poor at Guntur and in 2000-01 Patancheru experiment, and the contribution was 20% and 14%, respectively. The harvest index mean was high in these locations and therefore the contribution of harvest index to seed yield was low.

The commonly used stability analysis of Eberhart and Russell (3) was performed and the components (intercepts and slopes) of regression of RIL yield upon the environmental mean yield were obtained. A clustering approach was adapted to classify the RILs into various response groups. The extent of terminal drought experienced by the crop was severe at the three peninsular Indian locations compared to Kanpur. Moreover, those RILs performing the best under low yield environment are of particular importance as it is assumed that under constantly receding residual soil moisture, drought is the major yield-limiting factor. The means of the cluster groups showed considerable variation for the intercepts and slopes. At 50% dissimilarity level, the dendrogram showed 5 distinct groups (Table 4). Group I (30% of entries) with the parent Annigeri as a member, and 3 (8%) had the lowest intercepts and high slopes indicating that these were drought susceptible. Group 2 (27% RILs) had moderate levels of intercept and slope (about 1). Group 4 (33% of the RILs) had high intercept, with slopes similar to that of group 2, indicating that these were stable under most locations. However, ICC 4958 alone was placed in group 5, with best intercept and the least slope, confirming the drought tolerance response documented earlier (11). The fitted values of the seed yield of RILs for Guntur, the lowest yielding environment, were significantly correlated with the root dry weight of these RILs recorded under field conditions during 2001-02 at Patancheru (0.201^*, n = 142) (15), indicating a likelihood that the potentially large rooting RILs were able to yield better under lowest yielding environments.

A large RIL by location interaction existed for the seed yield and shoot biomass production and thus the RILs best adapted to each location varied indicating the need for selections for narrow target environments. The mean location yield of the parents and the RILs were the highest in 2000-01 at Patancheru and at Kanpur. The high shoot biomass production at Kanpur did not adequately reflect in seed yield due to poor partitioning and therefore these parents and the RILs are not the best suited for this environment. The heritability of yield and shoot biomass was low compared to that of the harvest index. The heritability was low at locations where other stresses such as limited growing period due to late sowing and poor partitioning operated along with terminal drought stress. The low heritability of seed yield and shoot biomass indicated that conventional breeding for these traits could be difficult with a very low probability of success. Thus, identification of molecular markers for these traits could lead to better marker-aided selections and to better yield stability. Variations both in shoot biomass production and harvest index equally accounted for the yield variation at all the locations except at Kanpur. At Kanpur, the yield was negatively related to shoot biomass production. These observations emphasized that equal importance should be placed both on final shoot biomass production and harvest index as a selection criterion. As biomass partitioning was the major limitation at Kanpur, higher harvest index should be the main criterion for selection at this location. The existence of large RIL x location effects, the changes in the processes that contribute to yield formation across

Table 4. **Group means ofintercepts and slopes of the RIL derived by regressing RILs means against environmental means and by clustering the RILs based on the intercepts and slopes**

Group number	Intercept	Mean yield of the group at lowest yield environment	Slope	RILs
1	-80.7	1083	1.033	RILs 1,7, 13, 19, 20, 24, 33. 38, 41. 56, 62, 66, 70. 79, 81, 112, 115. 122, 127, 130, 136, 140, 151, 164, 165, 184, 190, 192, 203, 208, 209. 210, 216, 227, 233, 237, 238, 239, 247, 250 and Annigeri.
2	7.7	1129	0.996	RILs 6, 10, 12, 18, 29, 30, 53, 67. 72, 84, 88, 93, 94, 96, 101, 103, 114, 116, 123, 128, 131, 135, 138. 142, 143, 155, 161, 163, 173, 174, 178, 181, 195, 201, 226, 228, 230. 234 and 244.
3	-164.2	1030	1.060	RILs 40, 73, 75, 90, 91, 113, 172, 204, 206, 207 and 256.
4	55.2	1179	0.998	RILs 4, 14, 15, 21, 28, 34, 35, 43, 44, 45, 46, 49. 50, 61, 78, 85, 87, 92, 106, 111, 117, 118, 120, 125. 132, 149, 150, 152, 157, 176, 191, 194, 196, 198, 205, 212, 213, 214. 222, 235, 236. 240, 242, 248 and 251.
5	192.2	1256	0.945	ICC 4958

locations and low heritability of seed yield suggests that it could be difficult to find adequate variation for seed yield with this mapping population under drought. But efforts towards molecular markers identification for drought tolerance on the basis of yield stability need to be continued with narrower range of target regions and alternate populations with adequate polymorphism.

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LITERATURE CITED

1. Brockwell, J. 1982. Inoculation methods for field experimenters and farmers. *In* : Vincent, J.M. (Eds.) Nitrogen Fixation in Legumes. Academic Press, New York, pp. 211-221.
2. Cui, K. H., Peng, S.B., Xing, Y.Z., Xu, C.G., Yu, S.B. and Zhang, Q. 2002. Molecular dissection of seedling-vigor and associated physiological traits in rice. *Theoretical and Applied Genetics* 105 : 745-753.
3. Eberhart, S.A. and Russell, W.A. 1966. Stability parameters for comparing varieties. *Crop Science* 6 : 36-40.
4. FAO, 2003. http://apps.fao.org. (Food and Agriculture Organization of the United Nations) 2002. FAO Production year book. Rome, Italy: FAO
5. Karnoshita, A., Wade, L.J., Ali, M.L., Pathan, M.S., Zhang, Z., Sarkarung, S. and Nguyen, H. T. 2002. Mapping QTLs for root morphology of a rice population adapted to rainfed lowland conditions. *Theoretical and Applied Genetics* 104 : 880-893.
6. Krishnarmurthy, L., Johansen, C. and Sethi, S.C., 1999. Investigation of factors determining genotypic differences in seed yield ofnon-irrigated and irrigated chickpeas using a physiological model of yield determination. *Journal of Agronomy & Crop Science* 183 : 9-17.
7. Kumar, J. and Abbo, S. 2001. Genetics of flowering time in chickpea and its bearing on productivity in semiarid environments. *Advances in Agronomy* 72 : 107-138.
8. Levitt, J. 1980. Responses of plants to environmental stresses. In: Kozlowski, T.T. (Ed.). Water, Radiation, Salt, and Other Stress. A series of monographs, Volume II, Texts and Treatises. Academic Press, New York, pp 25-280.
9. Mambani, B. and Lal, R. 1983. Response of upland rice varieties to drought stress. I. Relation between root system development and leaf water potential. *Plant and Soil* 73 : 59-72.
10. Saxena, N.P., Natarajan, M. and Reddy, M.S. 1984. Chickpea, Pigeonpea and Groundnut. Pages 281-305 in Symposium on Potential productivity of Field Crops under Different Environments. International Rice Research Institute, Los Banos, Laguna, Philippines.
11. Saxena, N.P. 1987. Screening for adaptation to drought: case studies with chickpea and pigeonpea. *In*: Adaptation of chickpea and pigeonpea to abiotic stresses. Proceedings of consultant's workshop. Patancheru 502 324, Andhra Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics. pp. 63-76.
12. Saxena, N.P. 2003. Management of drought in chickpea -A holistic approach. *In*: Saxena, N.P. (Ed.). Management of agricultural drought: Agronomic and genetic options. Oxford & IBH Publishing co. Pvt. Ltd., New Delhi, pp. 103-122.
13. Saxena, N.P., Krishnamurthy, L. and Johansen, C. 1993. Registration of a drought-resistant chickpea gennplasm. *Crop Science* 33 : 1424.
14. Serraj, R., Bidinger, F.R., Chauhan, Y.S., Seetharama, N., Nigam, S.N. and Saxena, N.P. 2003. Management of drought in ICRISAT cereal and legume mandate crops. In: Kijne, J.W., Barker, R., and Molden, D. (Eds.). Water Productivity in Agriculture: Limits and Opportunities for Improvement. Wallingford, UK: CABI, pp 127-144.
15. Serraj, R., Krishnamurthy, L., Kashiwagi, J., Kumar, J., Chandra, S. and Crouch, J.H. 2004. Variation in root traits of chickpea

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(*Cicer arietinum* L.) grown under tenninal drought. *Field Crop Research* (in press).

16. Serraj, R., Buhariwalla, H.K., Sharma, K.K., Gaur, P.M. and Crouch, J.H. 2004. Crop Improvement of drought resistance in pulses: A holistic approach. *Indian Journal of Pulses Research* **17**(1) : 1-13.
17. Singh, K.B., Bejiga, G., Saxena, M.C. and Singh, M. 1995. Transferability of chickpea selection indices from nonnal to drought-prone growing conditions in a mediterranean environment. *Journal of Agronomy & Crop Science* **36** : 472-479.
18. Srinivasan, A., Johansen, C. and Saxena, N.P. 1998. Cold tolerance during early reproductive growth of chickpea (*Cicer arietinum* L.): Characterization of stress and genetic variation in pod set. *Field Crops Research* **57** : 181-193.
19. Soltani, A., Ghassemi-Golezani, K, Khooie, F.R. and Moghaddam, M. 1999. A simple model for chickpea growth and yield. *Field Crops Research* **62** : 213-224.
20. Turner, N.C., Wright, G.C., Siddique, K.H.M., 2001. Adaptation ofgrain legumes (Pulses) to water limited Environments. *Advances in Agronomy* 71 : 193-231.
21. White, J. W., Castillo, J.A. 1992. Evaluation of diverse shoot genotypes on selected root genotypes of common bean under soil water deficits. *Crop Science* 32 : 762- 765.