Pak. J. Bot., 41(4): 1883-1890, 2009.

GENOTYPE X ENVIRONMENT INTERACTION FOR SEED YIELD IN KABULI CHICKPEA (*CICER ARIETINUM* L.) GENOTYPES DEVELOPED THROUGH MUTATION BREEDING

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Abstract

Elite lines of kabuli chickpea developed through mutation breeding at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad were evaluated for stability of grain yield at four diverse locations in the Punjab province during 2003-04, 2004-05 and 2005-06. The genotype yield, regression coefficient (bi), deviations from regression (S^2d) with sustainability index was used to identify the stable genotypes. Analysis of variance showed highly significant differences for environment (location, year), genotype and their interactions. Genotype x environment interaction (G x E) was of crossover in type. Mean seed yield performance in 12 environments indicated the superiority of mutant CM256/99 which produced the highest seed yield of 1349 kg ha^{-1} followed by CM305/99 (1344 kg ha^{-1}). The CM256/99 and CM305/99 were having non-significant high bi and S^2d values coupled with high sustainability index. This showed that both mutants were better responsive to the favorable environments. CM315/99 produced above average yield with non-significant unit regression and deviations from regression with highest sustainability index (75.41%). This mutant was also adapted to high performing environments. Pb.1 and CM2000 (Checks) contradict with respect to the stability parameters and the sustainability index. According to the Eberhart & Russell model of stability analysis, Pb.1 was a stable genotype but had only moderate (53.55%) sustainability index and *vice versa* for CM2000. So, both the Eberhart & Russell model and sustainability index cannot be considered simultaneously for predicting the stable genotypes. CM102/99 had low and non-significant bi and S^2d values indicated its better response to poor environment. Pb.1, CM2000 and CM102/99 produced below average yield. The mutants CM256/99, CM305/99 and CM315/99 had shown stable performance under different locations by having above average seed yield, non-significant unit regression co-efficient along with the non significant variance due to deviation from regression.

Introduction

Chickpea (*Cicer arietinum* L.) is a cool season legume that ranks third among the pulses in area and production worldwide. It is grown on around 1.1 m ha with 9 m.t global production. Asia is the most important chickpeaproducing continent with more than 90% of the total area and production.

Chickpea, mungbean, mashbean and lentil are important legume crops of Pakistan. Chickpea accounts for more than 80% of the area and production of all grain legumes grown in the country. In Pakistan chickpea is grown on >1.0 million hectares with annual production of 0.53 million tonnes. The Punjab province alone contributed 900.1 thousand ha which was 87.4% of the total chickpea area grown in the country (Anon., 2005-2006). Chickpea is a good source of good quality protein thus enhancing the nutritional value of cereal-dominated diet. It restores the fertility of the soil through symbiotic nitrogen fixation. It is successfully grown on marginal lands with low moisture constraints where no other crop can be grown economically. Chickpea is of two types, desi and kabuli. The former is generally small seeded with colored seed coat and angular seed shape, while the later is generally large seeded with beige seed color and rams' head shape. Both are botanically similar but there is strong preference in one or the other (Haq *et al.,* 2002). Chickpea after dehulling is valued for its nutritive seeds with high protein content (12.3-31.5%). Chickpea seeds are eaten fresh as green vegetables, parched, fried, roasted and boiled as snack food, sweet and condiments (Dawar *et al*., 2007).

Chickpea, like many other legumes, received very little attention in the past from the genetic improvement point of view. This had been mainly due to the scarcity of genetic variability in the world stock of germplasm. Chickpea has faced tough competition in recent years with cereal crops, where high yielding and inputs responsive varieties are available. The contribution of kabuli chickpea is 15% in Pakistan, which is further decreasing due to lack of bold seeded high yielding varieties and susceptibility to diseases. As a result the price of kabuli chickpea remains high and we have to spend 2875 million rupees during 2005-06 on its import. The main constraints to low yield are low yield potential of the existing cultivars and susceptibility to diseases particularly *Fusarium* wilt and *Ascochyta* blight. The blight epidemics of 1979-80, 1980-81, and 1981-82 reduced chickpea production by 48, 46 and 46%, respectively (Malik & Bashir, 1984; Malik *et al*., 1991). Farmers suffered losses of over three billion rupees from 1979 to 1982. The shortfall in domestic consumption was met through imports of 282,000 tonnes of pulses costing almost two billion rupees in foreign exchange (Malik, 1984). The best way to control chickpea blight is using resistant cultivars (Shah *et al.,* 2005). At NIAB, screening of advanced lines for resistance to this disease is done through creating artificial epiphytotic conditions of *Ascochyta* blight. From 1983-2006 researchers have developed and released 13 varieties of chickpea in Punjab, which are resistant to the deadly chickpea blight. Resistant varieties helped to increase and stabilize the production and productivity of chickpea. About 10-50% losses by *Fusarium* wilt have been reported on chickpea in the dry areas of Pakistan during the past several years (Khan *et al.,* 2002a). No economical chemical control measure is available. The use of resistant cultivars is the best and the cheapest method to minimize losses caused by wilt (Bakhsh *et al.,* 2007). On a global basis, annual yield losses in chickpea were estimated to be 4.8 million tonnes due to biotic stresses (Ryan, 1997). Resistance to *Fusarium* wilt in kabuli germplasm is limited, some accessions with high resistance have been identified (Gaur *et al.,* 2006).

At NIAB, since 1974, major efforts are underway to enhance/stabilize the chickpea productivity in the country by breeding disease resistant high yielding cultivars. An integrated approach to chickpea improvement is persued involving the creation of desirable genetic variability through the use of mutagens, hybridization and evaluation of the material using effective and efficient screening techniques and clear rating scales. As a result of these efforts high yielding and disease resistant varieties viz., CM 72 (1983), CM 88 (1994), CM 98 (1998) and CM 2000 (2000) have been evolved.

The genetic base of kabuli chickpea is very narrow in Punjab province where only three varieties have been released before the partition of Pakistan. First variety was Punjab 1 that was released during 1926 (Ali *et al*., 2002), second was Noor 91 released by AARI, Faisalabad in 1991 (Tufail & Yousaf, 1992) and the third and the last was CM2000 released by NIAB, Faisalabad during the year 2000 (Haq *et al.,* 2002). In order to increase the production of kabuli chickpea in the country and to curtail the import bill, there is great need to breed varieties with better plant type, high grain yield, wider adaptability, disease resistance through induced mutation and related breeding techniques. At present some advance mutants of kabuli chickpea have been developed at NIAB through the use of mutations and tested in multilocation yield trials. This will result in the identification of high yielding and widely adapted and disease resistant kabuli chickpea mutants that will improve chickpea productivity.

The performance of crop plants varies in different environments which indicate their adaptability to specific region or over wide areas (Khan *et al*., 2002b). With the help of statistical techniques developed to estimate stability parameters, it is possible to determine genotypic response for wider adaptability. Eberhart & Russell (1966) model had been widely used to study stability parameters. With the advancement of statistical techniques, methods are available for analysis of G x E interactions which consists of complementary procedures of classification and grouping the genotypes according to their response in different environments (Tuteja, 2006). Berger *et al*., (2007) listed 30 publications that reported highly significant G x E interaction for yield, which suggests that the issue is important in chickpea.

Most of the previous studies on G x E interactions were conducted on desi chickpea but the information of GxE in kabuli chickpea is not available, so this study has been among the first reports from Pakistan. In the present investigation, an attempt was made to study the stability for seed yield of kabuli chickpea mutants across diverse agro-ecological conditions in Punjab province of Pakistan and to compare Eberhart & Russell model (1966) and the new model based on sustainability index.

Materials and Methods

Four elite lines of kabuli chickpea (CM256/99, CM305/99, CM315/99 and CM102/99) developed through mutation breeding at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad along with two check cultivars (Pb.1 and CM2000) were evaluated for stability of grain yield at four diverse locations in the Punjab province viz., NIAB Faisalabad, BARI Chakwal, AZRI Bhakkar and ARF Karor Layyah during 2003-04, 2004-05 and 2005-06. The experiments were laid out in complete block design with three replications having a plot size of 6.0 m^2 keeping row and plant distance as 30 and 15 cm, respectively. Normal agronomic and cultural practices prevailing with the local requirements were applied at each location. Data were collected for seed yield per plot (g) from different locations and converted to Kg ha^{-1}. The data were analyzed as a split-split plot with locations as main plots, years as sub-plots and genotypes as sub-sub plots according to Steel & Torrie (1985). Stability parameters were estimated by using the Eberhart & Russell model (1966). The sustainability index was estimated by the following formula used by other workers (Singh & Agarwal, 2003; Gangwar *et al*., 2004; Tuteja, 2006).

$$S.I = \frac{Y - \sigma n}{Y_M} \times 100$$

where Y = Average performance of a genotype, σn = Standard deviation and Y_M = Best performance of a genotype in any year.

The values of sustainability index were divided arbitrarily into 5 groups viz. very low (upto 20%), low (21-40%), moderate (41-60%), high (61-80%) and very high (above 80%).

Table 1. Characteristics of the experimental material used in the study.

S. No.	Genotypes	Mutant/ variety	Pedigree	100 seed weight	Blight rating (NIAB)	Wilt rating (AARI)
1.	CM256/99	Mutant	M_8, Pb.1, Gamma rays, 200Gy	24.3	5	5
2.	CM305/99	Mutant	M_8, Pb.1, 0.2% EMS	23.3	5	5
3.	CM315/99	Mutant	M_8, Pb.1, 0.2% EMS	24.8	5	5
4.	CM102/99	Mutant	C_8, Pb.1, 0.05% Colchicine	23.3	5	5
5.	Pb-1	Check	Selection from local collection	18.0	9	9
6.	CM2000	Check	ILC195, Gamma rays, 150Gy	26.8	5	9

Table 2. Analysis of variance for seed yield (kg/ha) in six kabuli chickpea genotypes grown at four locations for three years.

Source	Degree of freedom	Mean square
Factor A (Location)	3	14761771.51**
Error	6	10384.88
Factor B (Year)	2	5831240.43**
AB (Location x Year)	6	4603337.94**
Factor C (Genotype)	5	311245.64**
AC (Location x Genotype)	15	136898.45**
BC (Year x Genotype)	10	71348.12*
ABC (Location x Year x Genotype)	30	147032.57**
Error	136	37196.53
Total	215	
Coefficient of variation:	15.43%	

*, **= Significant at 5% and 1% levels, respectively.

Results and Discussion

Main characteristics of the experimental material used in the study has been presented in Table 1. All the four kabuli chickpea mutants were moderately resistant to *Ascochyta* blight and *Fusarium* wilt with 100 seed weight above 23 g. The analysis of variance for seed yield displayed highly significant differences among locations, years, genotypes and location x year, location x genotype and location x year x genotype interactions and significant for year x genotype interactions advocating the adequacy of stability analysis (Table 2). This showed that the genotypes were not only genetically variable but some of them also exhibited different response to variable environments (locations and years). The partitioning in pooled analysis of variance showed that varieties x environments interaction was significant (Table 3). Environment linear and varieties x environment linear were highly significant. Arshad *et al.*, (2003) also reported highly significant genotype x environment (G x E) interaction in chickpea. A significant G x E interaction may be either crossover, in which a significant change in rank occurs from one environment to another (Matus *et al.*, 1997) or a non crossover G x E interaction, in which the ranking of genotypes remains constant across environments and the interaction was significant because of change in the magnitude of response (Baker, 1988; Blum, 1983; Matus *et al*., 1997). In the present study the significant G x E interaction seems to be of a crossover nature.

Overall mean values for grain yield varied from 367-2943 kg ha^{-1}. Mean values in grain yield ranged from 1141-1348 kg ha^{-1} for genotypes, 936-1490 kg ha^{-1} for years and 728-1788 kg ha^{-1} for locations (Data not shown). The variation in yields between locations was higher as compared to those in genotypes and years. Our results contradicted with those of Ulker *et al*., (2006) who reported higher variation in yields between years compared to those in genotypes and locations.

Mean seed yield performance of four environments for 3 consecutive years (Table 4) indicated the superiority of mutant CM256/99 by producing seed yield of 1349 kg ha^{-1} followed by CM305/99 (1344 kg ha^{-1}). Both the mutants gave significantly higher yield as compared to the Pb.1 and CM2000 check varieties. CM315/99 (1294 kg ha^{-1}) and CM102/99 (1221 kg ha^{-1}) gave higher but non-significant yield from CM2000 and from both the check varieties, respectively.

Finlay & Wilkinson (1963) reported that the regression coefficient 'b' is a measure of stability in crop plants. Eberhart & Russell (1966) proposed that both regression coefficient 'b' and deviation from regression coefficient 'S^2d' may be taken into consideration in identifying a stable genotypes. So, a genotype with 'b' value <1.0 has above average stability and is specially adapted to low-performing environments, a cultivar with 'b' value >1.0 has below average stability and is specially adapted to high performing environments and a cultivar with 'b' value equal to 1.0 has average stability and is well or poorly adapted to all environments depending on having a high or low mean performance (Finlay & Wilkinson, 1963) but a genotype with $b = 1.0$ and $S^2d = 0.0$ may be defined as stable (Eberhart & Russell, 1966).

CM256/99 and CM305/99 were having high yield with non-significant high 'bi' and 'S^2d' values (Table 4). This showed that both mutants were better responsive to the favorable environments. CM315/99 produced above average yield with non-significant unit regression and deviations from regression, this mutant was also adapted to high performing environments. CM102/99 had low and non-significant bi and S^2d values indicated its better response to poor environment. The mutants CM256/99, CM305/99 and CM315/99 produced 17.20, 16.76 and 12.42% higher yield from the better check variety CM2000 and 7.92, 7.52 and 3.52% higher yield respectively, from the overall mean seed yield of the experiment. Pb.1, CM2000 and CM102/99 produced below average yield. The regression coefficient of Pb.1 was close to unity (1.07) and showing non significant differences from unit regression (b) and also had the lower variance due to deviation from regression (S^2d). So, Pb.1 check cultivar is a stable variety but had low and below average yield. Based on Eberhart & Russell (1966) model, the mutants CM256/99, CM305/99 and CM315/99 appeared to be the most stable. Stability in the seed yield had been earlier reported by Singh & Bejiga (1990), Arshad *et al*., (2003) and Bakhsh *et al.,* (2006) in chickpea and by Saleem *et al*., (2002), Raje & Rao (2004) and Swamy & Reddy (2004) in mungbean.

Sustainability index was also used to identify the stable genotypes. The average yield, standard deviation and the sustainability index of each genotype has been given in the Table 5. High sustainability index (%) was estimated in the case of CM315/99 (75.41) followed by CM102/99 (70.82), CM2000 (65.50), CM305/99 (64.54) and CM256/99 (62.09), whereas moderate sustainability index was observed in the check variety Pb.1 (53.55).

Table 3. Pooled analysis of variance for grain yield in kabuli chickpea.

Source	Degree of freedom	Mean square
Total	71	433342.09**
Environments	11	2532357.75**
Varieties	5	103747.20**
Var. x Env.	55	43502.14*
Env. + Var. x Env.	66	458311.40**
Env. (Linear)	1	27855942.00**
Var. x Env. (Linear)	5	141294.45**
Pooled Dev.	60	28102.29
Pooled Error	144	36577.25

*, **= Significant against pooled deviation M.S. at 5 and 1% levels, respectively.

Table 4. Stability parameters for grain yield in kabuli chickpea.

Genotype	Mean seed yield (kg/ha)	Regression coefficient (bi)	Deviation from regression (S^2d)
CM256/99	1349 a	1.15	31290.40
CM305/99	1344 a	1.12	13561.30
CM315/99	1294 ab	1.09	16943.15
CM102/99	1221 abc	0.82	35574.55
Pb-1	1141 c	1.07	27470.19
CM2000	1151 bc	0.73*	43774.17
Mean	1250		

Mean values carrying similar letter(s) do not differ significantly at 5% level of probability.

Table 5. Estimates of sustainability index for grain yield in kabuli chickpea.

Genotype	Mean yield (kg/ha) Y	Standard deviation σn	Best performance of a genotype in any year Y_M	Sustainability Index (%) S.I = Y-σn/ Y_M x 100
CM256/99	1349	335	1633	62.09
CM305/99	1344	312	1599	64.54
CM315/99	1294	250	1517	75.41
CM102/99	1221	250	1371	70.82
Pb-1	1141	351	1495	53.55
CM2000	1151	285	1322	65.50

The comparison of Eberhart & Russell (1966) model with the new model based on sustainability index (Table 6) revealed that Pb.1 and CM2000 (Checks) contradict with respect to the stability parameters and the sustainability index. According to the Eberhart & Russell model of stability analysis, Pb.1 was a stable genotype but had only moderate (53.55%) sustainability index and rated on the last position, whereas CM2000 was unstable according to the first model but was having high sustainability index with third position in rating. So, on the basis of mean seed yield, Eberhart & Russell (1966) model and sustainability index cannot be considered simultaneously for predicting the stable genotypes in chickpea. In the present studies Eberhart & Russell (1966) model was found to be more robust for predicting the stable genotypes.

Table 6. Comparison between the Eberhart & Russell model and Sustainability Index.

Genotype	Mean yield	Eberhart & Russell Model			Sustainability Index	
		(bi)	(S^2 d)	Rating	S.I (%)	Rating
CM256/99	1349	1.15	31290.40	Stable	62.09	High
CM305/99	1344	1.12	13561.30	Stable	64.54	High
CM315/99	1294	1.09	16943.15	Stable	75.41	High
CM102/99	1221	0.82	35574.55	Stable[1]	70.82	High
Pb-1	1141	1.07	27470.19	Stable[1]	53.55	Moderate
CM2000	1151	0.73*	43774.17	Unstable[1]	65.50	High
Mean	1250					

[1] = Below average yield

The genotypes differ in their response for the stability parameters. Singh & Bejiga (1990) concluded that cultivars have to be bred separately for favourable and unfavourable environments. The stable genotypes with respect to the seed yield under variable environments may be useful for direct release as a variety or in a breeding program for evolving high yielding chickpea varieties adapted to this zone. The mutants CM256/99, CM305/99 and CM315/99 had shown stable performance under different locations by having above average seed yield, non-significant unit regression co-efficient along with the non-significant variance due to deviation from regression. These mutant(s) may be suitable for cultivation in the Punjab province during rabi season after release as a variety(s).

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(Received for publication 13 July 2008)