Korean J. Plant Res. 20(6) : 504~510(2007)

Genotype-Environment Interaction and Stability Analysis for Yield and Yield Contributing Characters in Soybean (*Glycine max* L.)

Mohammad Saiful Islam, Muhammad Ali Newaz[1], Md. Jahidul Islam[2], Seong-Il Heo and Myeong Hyeon Wang*

School of Biotechnology, Kangwon National University, Chuncheon, Kangwon 200-701, Korea

[1]Dept. of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh, Bangladesh

[2]Dept. of Agricultural Chemistry & Biochemistry, HSTU, Dinajpur, Bangladesh

Abstract - GE interaction is the expression of differential genotypic adaptation across environments. GE interactions through different stability parameters and performance of the traits of genotypes were studied. The traits were days to maturity, pod length, number of pods/ plant, 100-seed weight and seed yield/plant in ten soybean genotypes across five environments. Significant differences were observed for genotypes, environments and GE interactions. Stability analysis after Eberhart and Russell' s model suggested that the genotypes used in this study were all more or less responsive to environmental changes. Most of the genotypes perform better in Env.3. Based on phenotypic indices (Pi), regression (S^2di) genotype Garurab was found fairly stable for days to maturity. BS-23 and G-2120 may be considered as stable genotype for pod length. All the genotypes except G-2120 showed that the genotypes were relatively unstable under environmental fluctuation for the number of pod/plant. Genotype BS-23 was found most stable among all the genotypes for 100-seed weight. BS-3 and Gaurab was the most stable and desirable genotypes for seed yield in soybean.

Key words - Soybean, Genotype- environment- interactions and stability

Abbreviations - Pi, Phenotypic index; bi, Regression coefficient; S^2di, Deviation from regression

Introduction

Soybean (*Glycine max* L.) is an important leguminous crop and has a tremendous value in agriculture as a good source of high quality plant protein and vegetable oils in one hand and nitrogen fixing ability on the other hand. A key issue in plant breeding is the selection of genotypes that perform well in target agricultural environments. This can be achieved by selecting germplasm that has broad adaptation across environments or by classifying environments and identifying genotypes that perform well in particular types of environments. Gene expression is subject to modification by the environment; therefore, genotypic expression of the phenotype is environmentally dependent (Kang, 1998).

GE interactions also impact selection of superior genotypes for fiber quality in cotton performance trials (Paterson *et al.,* 2003). Preferred genotypes generally show GE interactions variances, above average response to environmental yield potential and lower deviations from the expected response within a target production region (Kang, 2002). A study of GE interaction is of much value in the selection of better genotypes. Specific genotypes respond differently depend on environmental condition. In dealing with instability and uncertainty of yield and in developing improved varieties for wide adaptation, genotype-environment interaction is of major consideration for crop improvement (Eberhart and Russell, 1966). Stability analysis is a good technique for measuring the adaptability of different crop varieties to varying environments (Morales *et al.,* 1991). A stable genotype is one which displays unit regression co-efficient and the deviation from regression as small as approaching to zero. Hence the definition of a stable variety according to Eberhart and Russell' s model is one with bi = 1 and $S^2d = 0$. According to Langer *et al.* (1979) the regression coefficient is a measure of response to varying environments and deviation from regression is a true measure of prediction of stability. The regressions of yield of cultivars upon means of sets of cultivars over diverse environments are often used as measures of stability/adaptability (Simmonds, 1991). Currently, there is a growing awarness about the importance of genotype-environment interaction affecting varietal performance as well as the breeding

*Corresponding author. E-mail : mhwang@kangwon.ac.kr

program. So, identification of the causal factors of the GE interaction and quantification of unexplained variation are very important for identifying factors affecting stability and adaptation to specific environmental conditions (Epinat-Le Signor *et al.*, 2001). The present investigation was therefore, undertaken to study GE interaction and to identify both high yielding and stable genotypes over environmental changes in soybean.

Materials and Methods

Experimental details

Ten genotypes of soybean namely BS-23, BS-16, COBB, BS-15, Colombus, BS-60, BS-3, PB-1, G-2120 and Guarab were grown in a randomized complete block design with three replications under five artificially created environments in the summer soybean growing season, 2006, at experimental farm, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. The texture of the soil was silty loam having pH 6.7 (FAO and UNDP, 1998). The environments were artificially created by application of different chemical fertilizer packages, inoculums and cowdung. The created environments were Env-1: Manure (cowdung), Env-2: Inoculum + TSP (Triple Super Phosphate) + MP (Murate of Potash), Env-3: Urea + TSP + MP. Env-4: Inoculum + Urea + TSP + MP and Env-5: Control. The rates of inputs for created environments were Rhizobium inoculants (for seeds) @ (at the rate of) 30g/kg, manure @ 4000kg/ha, Urea @ 60kg/ha, TSP @ 140kg/ha and MP @ 70kg/ha. The unit plot size in a replication measured 4m in length and 0.75m in width, accomoding 3-rows of 240 plants per genotype keeping row to row distance 25cm and plant to plant distance 5cm. Normal cultural practices were followed as and when necessary.

Sampling procedures

At maturity, data were recorded from middle row and on an individual plant basis from 10 randomly selected plants per genotype in a replicate. The crop was harvested when 90% of the plants with mature pods of genotypes withered and turned brown. The criteria used in recording of data are as follows; (a) Days to maturity: Recorded as day on plot basis from seedling to the time when about 90% of the plants were ready for harvesting, (b) Number of pods/ plant: Both fertile and empty pods from 10 randomly selected plants per genotype were counted and averaged over 10 plants. (c) Pod length: Pod length was measured from 10 randomly selected pods per genotype. (d) 100-seed weight: After harvest, seeds were sun dried and cleaned. Hundred seeds were randomly selected and weight was taken in gram. (e) Seed yield/ plant: The average weight of seeds per plant was measured and expressed in gram at 9～12% moisture level.

Statistical analysis

The genotype- environment interactions and stability analysis were done following the method suggested by (Eberhart and Russel, 1966), also quoted by (Singh and Chaudhary, 1985; Dabholkar, 1992).

Results and Discussion

The results of the combined analysis of variance for five traits such as days to maturity, pod length, number of pods/ plant, 100-seed weight and seed yield /plant after the Eberhart and Russell' s model are presented in Table 1. The mean squares for genotypes and environments (linear) for all the traits under study were highly significant ($p<0.01$), suggesting the existence of considerable variation among genotypes as well as environments. The genotype-environments interaction (linear) when tested against pooled error it was found significant for all the characters except (pod length), indicating that all the traits were highly influenced by the change in environments leading to extension of analysis for estimating stability parameters. Result showed that the pod length was non-significant against both pooled deviation and pooled error. It indicates that cultural environments did not influence pod length. Days to maturity, 100 seed weight and seed yield/ plant were significant mean square due to both pooled deviation and genotype × environment interactions (linear) indicates that part of variability was unpredictable in nature. It was found that significant genotype x environment interaction for seed yield, 100 seed weight and days to maturity in Sweat Buckwheat (Sharma *et al.*, 2002). Significant differences were also observed among the genotypes and genotype × environment interactions for dry bean (Islam and Newaz, 2001), Pea (Gupta *et al.*, 1998).

The combined analysis of variance showed that the linear components of GE interaction were significant for five traits except pod length. While non-linear components were non significant for all the traits. This indicated that variation among the performance of genotypes was entirely unpredictable. Ibrahim and Bukenbaur mentioned that relatively unpredictable interaction is of greater importance than the relatively predictable component (Ibrahim and

Table 1. Combined analysis of variance for five characters in a genotype-environment interaction study in soybean after Eberhart and Russell' s model

Source of variations	d.f	Mean sum of square				
		Days to maturity	Pod length (cm)	Number of Pods/ plant	100 - seed weight (g)	Seed yield/ plant (g)
Genotypes	9	239.59**	0.45**	779.44**	93.1**	15.48**
Env+Gen × Env (non-linear)	40	23.47	0.15	46.39	7.98	1.55
Env. (linear)	1	225.57**	1.11**	1307.35**	124.23**	26.49**
Gen. × Env. (Linear)	9	4.36*	0.04	112.54**	3.86*	1.63**
Pooled deviation	30	9.94**	0.04	10.79	0.56*	0.29**
BS-23	3	1.14	0.08	3.43	0.89	0.02
BS-16	3	1.06	0.03	8.78	0.37	0.04
COBB	3	20.85**	0.02	5.58	0.99	2.18**
BS-15	3	22.93**	0.04	7.85	0.34	0.09
Colombus	3	44.79**	0.12*	6.59	0.28	0.06
BS-60	3	1.07	0.02	10.3	0.12	0.01
BS-3	3	0.93	0.02	6.51	2.02	0.13
PB-1	3	1.58	0.04	2.99	0.13	0.01
G-2120	3	1.90	0.08	30.28	0.29	3.30**
Gaurab	3	3.16	0.02	25.57	0.21	0.12
Pooled error	100	1.49	0.06	11.06	2.29	0.18

*P<0.05, ** P<0.01.

Bukenbaur, 1987). The results of stability and responses of the genotypes to different environments are described character wise as follows:

Days to maturity

The mean performances of the individual genotype along with their stability parameters (Pi, bi and S^2di) for maturity are presented in Table 2. From the environmental mean it was observed that Env.4 had the highest mean (108.0) and the lowest in Env.5 (104.7) for days to maturity, this indicated that Env.4 was the most favorable one. Over all the environments, genotype BS-16 gave the highest mean value (111.73) and lowest in BS-23 (101.73) it appeared that genotypes BS-16 is the late maturating and BS-23 is the early maturating genotypes among the genotypes studied. Genotypes BS-23, Colombus, BS-60, BS-3, G2120 and Gaurab had the negative phenotypic indices therefore; they are desirable for this character. For days to maturity, the major portion of GE interaction was accounted for by the deviation from regression. It was observed that none of the genotypes showed significant bi value except BS-3 suggesting only non-linear component was responsible for GE interaction. Analysis of the stability parameters of the individual genotypes indicated that none of the genotypes exactly showed combined bi and S^2di sensitivity suggesting either liner or non-linear component alone or their cumulative effects were responsible for significant genotype environment interactions. Genotype BS-3 showed negative bi values with non-significant S^2di values; indicating its suitability only for favorable environmental condition (Env.4). COBB, BS-15 and Colombus showed significant S^2di values, thus prediction of their performance over environment would not be authentic. Considering all the three estimates of stability parameters, it appeared that genotype Guarab which have negative phenotypic indices with the regression co-efficient around unity and non significant S^2di value was the most stable genotypes among the genotypes studied.

Pod length

The stability parameter along with the average number of pod length in ten soybean genotypes and five environments are presented in Table 3. From the environmental mean it was observed that Env.2 was the favorable environment and the Env.5 was the

Table 2. Average days to maturity, response and stability parameters of ten genotypes of soybean evaluated under five environments using Eberhart and Russell' s model

Name of genotypes	Environments					Mean (x)	Pi	Bi	S^2di
	Env-1	Env-2	Env-3	Env-4	Env-5				
BS-23	101.0	100.6	102.0	102.0	103.0	101.73	-4.02	0.697	0.238
BS-16	111.0	111.0	112.0	113.0	111.0	111.73	5.98	0.946	-1.678
COBB	104.0	104.3	104.3	114.0	103.0	105.93	0.18	3.384	-1.634**
BS-15	111.0	111.0	113.0	113.0	103.0	110.20	4.45	2.042	12.002**
Colombus	100.0	100.3	102.0	114.0	103.0	104.00	-1.75	4.135	1.519**
BS-60	104.0	104.0	103.0	104.0	102.0	103.40	-2.35	0.487	-0.034
BS-3	104.0	104.0	103.0	102.0	103.0	103.20	-2.55	-0.243**	0.281
PB-1	111.0	110.6	113.0	112.0	113.0	111.00	5.25	0.476	0.514
G2120	102.0	101.3	104.0	103.0	104.0	102.88	2.87	0.490	0.793
Guarab	101.3	101.3	105.0	103.0	102.0	102.53	-3.22	0.869	0.766
Environmental mean	105.0	104.8	106.1	108.0	104.7	105.75			
Environmental index	-0.75	-0.88	0.38	2.25	-0.98				

Env. means environment, Env-1: Manure (cowdung), Env-2: Inoculum + TSP (Triple Super Phosphate) + MP (Murate of Potash), Env-3: Urea + TSP + MP, Env-4: Inoculum + Urea + TSP + MP and Env-5: Control. *, ** indicates significant at 5% and 1% level respectively.

Table 3. Average pod length (cm), response and stability parameters of ten genotypes of soybean evaluated under five environments using Eberhart and Russell' s model

Name of genotypes	Environments					Mean (x)	Pi	bi	S^2di
	Env-1	Env-2	Env-3	Env-4	Env-5				
BS-23	4.34	4.61	4.00	4.26	3.91	4.23	0.12	1.46	0.06
BS-16	4.13	4.10	4.40	3.87	4.17	4.13	0.02	-1.23*	0.01
COBB	4.05	4.27	4.00	4.00	4.07	4.08	-0.03	-0.07	-0.01
BS-15	4.16	4.62	4.43	4.36	4.28	4.37	0.06	-0.08	0.02
Colombus	4.30	4.27	3.75	3.64	3.55	3.90	-0.21	2.06	0.10
BS-60	4.25	4.03	4.15	4.48	4.17	4.23	0.12	-2.08**	-0.04
BS-3	4.20	4.44	4.05	4.28	4.27	4.25	0.14	-0.18	0.04
PB-1	4.29	4.23	4.22	3.93	3.90	4.11	0.00	0.10	0.02
G-2120	4.08	4.41	3.77	3.70	3.99	3.99	-0.12	1.50	0.06
Guarab	3.53	3.66	3.79	4.01	3.98	3.79	-0.32	-2.40**	-0.04
Environmental mean	4.13	4.27	4.06	4.05	4.03	4.11			
Environmental index	0.02	0.16	-0.06	-0.06	-0.08				

Env. means environment, Env-1: Manure (cowdung), Env-2: Inoculum + TSP (Triple Super Phosphate) + MP (Murate of Potash), Env-3: Urea + TSP + MP, Env-4: Inoculum + Urea + TSP + MP and Env-5: Control. *, ** indicates significant at 5% and 1% level respectively.

most unfavorable one. Genotypes BS-23, BS-16, BS-15, BS-60, BS-3 and PB-1 had the positive phenotypic indices; hence, they were desirable for this trait. Analysis of the stability parameters of the individual genotypes indicated that none of the genotypes showed combined bi and S^2di values exactly sensitivity suggesting either liner or non-linear component alone or their cumulative effects were responsible for significant genotype environment interactions BS-23, Colombus and G-2120 had the higher bi value (1.46, 2.06 and 1.49 respectively) with non significant S^2di indicating their suitability for growing in better environmental conditions. Genotype Guarab had the lowest bi values (-2.40) with non significant S^2di values that indicated that the genotype suited only for poor environmental condition. None of the genotype had significant S^2di values, so the performance of these genotypes under different environmental condition is predictable. Taking all the three stability parameters genotype BS-23 and G-2120 may be considered as stable and desirable genotypes for pod length because only these two genotypes showed bi value around unity and S^2di value nearly zero.

Number of pods / plant

The average number of pods / plant performance of the individual genotype along with stability parameters are presented in Table 4. From the environmental mean it was observed that Env.3 had the highest mean (26.57 / plant) and the lowest in Env.5 (19.07 / plant). This indicated that Env.3 was the most favorable one and the majority of the genotypes had the capacity to exploit that environment to confer the highest number of pod. Colombus, G-2120 and Gaurab showed positive phenotypic indices; therefore they are desirable for this character. Results showed that all the genotypes (except BS-23 and Colombus) showed bi values close to the unity indicating average responsive to diverse environments. All genotypes except G-2120 showed non-significant S^2di value which suggests that the genotypes are relatively unstable under environmental fluctuation.

100- Seed weight

The average 100-seed weight of individual genotypes over five environments with their phenotypic index; regression co-efficient and deviation from regression are presented in Table 5. From the environmental mean it was observed that most of the genotypes produced maximum100-seed weight when sown in Env.2 and about same in Env.3. The highest 100 seed weight (14.10) produced by the genotypes COBB and the lowest (6.90) produced by the genotypes Gaurab. The phenotypic indices of BS-23, BS-16, COBB, BS-15, BS-60 and BS-3 were positive, therefore they are desirable genotype for this character. Analysis of the stability parameters of the individual genotypes indicated that the genotypes BS-23 showed combined bi and S^2di sensitivity suggesting both liner and non-linear components were responsible for GE interactions. Results also found that the linear component of GE interaction was significant for 100-seed weight, whereas non-linear component was significant for grain yield and its components in mungbean (Noren Singh, 2003). All the genotypes (except PB-1, G-2120 and Gaurab) showed higher bi values indicating their suitability only for highly favorable environments. All the genotypes showed non significant S^2di values which suggested that genotypes are relatively stable under environmental fluctuation. Considering all the three parameters (pi, bi and S^2di) the genotype BS-23 was found most stable among all the genotypes having bi value near to unity and S^2di values also nearly zero with non-significant S^2di values.

Seed yield / plant

The average yield performance of the individual genotype along

Table 4. Average number of pods / plant, response and stability parameters of ten genotypes of soybean evaluated under five environments using Eberhart and Russell' s model

Name of genotypes	Environments					Mean (x)	Pi	Bi	S^2di
	Env-1	Env-2	Env-3	Env-4	Env-5				
BS-23	16.51	16.34	18.94	20.54	15.47	17.56	-5.72	0.413*	-0.328
BS-16	21.39	22.03	28.43	24.07	18.73	22.93	-0.35	0.773	5.015
COBB	16.87	20.54	23.49	23.53	16.95	20.28	-5.00	0.786	1.823
BS-15	14.30	17.29	20.65	23.50	14.49	18.05	-5.23	0.961	4.086
Colombus	25.55	27.55	31.57	27.79	24.62	27.46	4.18	0.453	2.835
BS-60	16.21	22.08	21.05	24.33	14.53	19.64	-3.64	0.920	6.542
BS-3	16.54	19.53	20.79	21.45	12.61	18.18	-5.10	0.877	2.746
PB-1	16.07	16.87	19.83	19.67	14.58	17.40	-5.88	0.527	-0.769
G-2120	38.13	38.52	42.50	35.33	28.09	38.52	13.24	0.742	26.518*
Guarab	27.59	34.00	38.43	43.28	30.62	34.79	11.51	1.342	21.808
Environmental mean	20.92	23.48	26.57	26.35	19.07	23.28			
Environmental index	-2.36	0.20	3.29	3.07	-4.21				

Env. means environment, Env-1: Manure (cowdung), Env-2: Inoculum + TSP (Triple Super Phosphate) + MP (Murate of Potash), Env-3: Urea + TSP + MP, Env-4: Inoculum + Urea + TSP + MP and Env-5: Control. *, ** indicates significant at 5% and 1% level respectively.

Table 5. Average 100-seed weight, response and stability parameters of ten genotypes of soybean evaluated under five environments using Eberhart and Russell' s model

Name of the genotypes	Environments					Mean (x)	Pi	bi	S^2di
	Env-1	Env-2	Env-3	Env-4	Env-5				
BS-23	9.67	11.33	11.67	13.33	12.66	11.73	0.70	1.115	0.110
BS-16	10.33	13.77	13.00	12.00	14.00	12.62	1.59	1.377	-0.404
COBB	10.67	15.50	14.67	15.67	14.00	14.10	3.07	1.806	0.214
BS-15	9.33	15.50	13.67	14.00	15.00	13.50	2.47	2.347**	-0.438
Colombus	6.67	12.00	11.33	10.00	12.00	10.40	-0.63	2.151**	-0.500
BS-60	9.67	11.87	12.33	12.67	12.33	11.77	0.24	1.152	-0.662
BS-3	9.67	11.33	14.73	12.00	13.73	12.29	1.26	1.583	1.247
PB-1	9.67	10.00	10.33	9.67	10.67	10.07	-0.96	0.293	-0.645
G2120	8.67	6.83	5.83	6.67	6.67	6.93	-04.10	-0.922**	-0.493
Guarab	8.00	6.67	7.17	6.67	6.00	6.90	-4.13	-0.617**	-0.571
Environmental mean	9.23	11.48	11.47	11.27	11.17	11.03			
Environmental index	-1.8	0.45	0.44	0.24	0.68				

Env. means environment, Env-1: Manure (cowdung), Env-2: Inoculum + TSP (Triple Super Phosphate) + MP (Murate of Potash), Env-3: Urea + TSP + MP, Env-4: Inoculum + Urea + TSP + MP and Env-5: Control. *, ** indicates significant at 5% and 1% level respectively.

Table 6. Average seed yield / plant (g), response and stability parameters of ten genotypes of soybean evaluated under five environments using Eberhart and Russell' s model

Name of the genotypes	Environments					Mean (x)	Pi	Bi	S^2di
	Env-1	Env-2	Env-3	Env-4	Env-5				
BS-23	2.73	3.53	3.63	2.93	2.87	3.14	-1.12	0.838	-0.043
BS-16	2.80	2.67	2.63	2.33	2.78	2.65	-1.61	-0.137**	-0.018
COBB	4.03	2.55	6.45	4.90	4.32	4.45	0.19	1.279	2.124**
BS-15	4.37	6.17	5.87	5.27	4.72	5.28	1.02	1.509	0.026
Colombus	4.03	5.17	4.87	4.57	4.12	4.55	0.29	0.935	-0.005
BS-60	2.60	4.03	4.10	3.30	3.02	3.41	-0.85	1.356**	-0.046
BS-3	3.17	3.50	4.50	3.43	2.74	3.47	-0.79	1.206	0.071
PB-1	4.27	5.27	5.37	5.10	4.53	4.91	0.65	1.039**	-0.069
G2120	4.53	6.05	5.13	5.73	5.15	5.32	1.06	0.733	0.244
Guarab	4.03	5.97	6.23	5.43	5.50	5.43	1.17	1.088	0.061
Environmental mean	3.66	4.50	4.88	4.30	3.97	4.26			
Environmental index	-0.60	0.24	0.62	0.04	-0.29				

Env. means environment, Env-1: Manure (cowdung), Env-2: Inoculum + TSP (Triple Super Phosphate) + MP (Murate of Potash), Env-3: Urea + TSP + MP, Env-4: Inoculum + Urea + TSP + MP and Env-5: Control. *, ** indicates significant at 5% and 1% level respectively.

with pi, bi and S^2di are presented in Table 6. From the environmental mean it was observed that Env.3 had the highest mean yield. (4.88g / plant) and the lowest in Env.1 (3.66g / plant). This indicated that Env.3 was the most favorable one and the majority of the genotypes had the capacity to exploit that environment to confer the highest yield. Over all the environments genotype Gaurab gave the highest yield (5.43g / plant) and lowest in BS-16 (2.65g / plant). The most predictable parameter was the phenotypic indices (Pi) of the individual genotypes. The highest phenotypic index was in Guarab (pi=1.17) while the lowest in BS-16 (pi = -1.61). The genotypes COBB, BS-15, Colombus, PB-1, G-2120 and Gaurab showed positive phenotypic index so desirable for selection. Analysis of the stability parameters of the individual genotypes indicated that none of the genotypes showed combined bi and S^2di sensitivity suggesting either liner or non-linear component alone or their cumulative effects were responsible for significant genotype environment interactions. Genotype BS-60 had the higher bi values which were significantly different from unity with non-significant S^2di values; so this genotype was highly responsible to environmental fluctuation and suitable for highly favorable environment (Env.4). The genotype COBB showed significant S^2d value, indicating that the performance of this genotype were not able to predictable. Based on three stability parameters into consideration, it was observed that BS-3 and Gaurab having $bi \approx 1$ and $S^2di \approx 0$ were most stable and desirable genotypes among all the genotypes.

In conclusion, this study showed the presence of and the type of GE interactions among the 10 soybean genotypes and their yield components. The study suggested that Garurab may be selected for stability in days to maturity. BS-23 and G-2120 may be considered as stable genotype for pod length. All the genotypes except G-2120 showed that the genotypes were relatively unstable under environmental fluctuation for the number of pod/ plant. Genotype BS-23 was found most stable among all the genotypes for 100 seed weight. BS-3 and Gaurab was found most stable and desirable genotypes for seed yield. These materials can be used in soybean breeding program as a source of genes for stability.

Literature Cited

Dabholkar, A.R. 1992. Elements of Biometrical Genetics. Concept publishing company. New Delhi. pp. 338-359.

Eberhart, S.A. and W.A. Russell.1966. Stability parameters for comparing varieties. Crop Sci. 6: 36-40.

Epinat-Le Signor, C., S. Dousse, J. Lorgeou, J.B. Denis, R. Bonhomme, P. Carolo and A. Charcosset. 2001. Interpretation of genotype × environment interactions for early maize hybrids over 12 years. Crop Sci. 41: 663-669.

FAO. and UNDP. 1998. Land resources appraisal of Bangladesh for agricultural development. Agro-ecological regions of Bangladesh report 4.UNDP/FAO. Rome pp. 212-221.

Gupta, M.K.,V.K. Mishra and J.P. Singh. 1998. Phenotype stability in pea. Crop Res.16: 97-101.

Ibrahim, K. and P. Bukenbaur. 1987. Stability parameters of important characters in various types of Faba bean. FABIS News letter 17: 10-13.

Islam, A. K. M. A. and M. A. Newaz. 2001.Genotype-environment interaction for seed yield and yield contributing characters in Dry Bean (*P. vulgaris* L.). Bangladesh J. Pl. Breed. Genet. 14: 43-48.

Kang, M.S. 1998. Using genotype-by-environment interaction for crop cultivar development. Adv. Agron. 35: 199-240.

Kang M.S. 2002. Genotype-environment interaction: progress and prospects. In: Quantitative Genetics, Genomics and Plant Breeding, (M.S. Kang, ed). CABI Pulishing. Wallingford. New York pp. 221-243.

Langer, S., K.J. Frey and T.B. Bailey. 1979. Association among productivity production response and stability index in oat varieties. Euphytica. 28: 17-24.

Morales, A.C, A. A. Paragas and V. R. Carangal. 1991. Phenotypic stability for grain yield in mungbean (*Vigna radiata* L. Wilczek). FLCG Newsletter 16: 12-15.

Noren Singh K., P. R. Sharma and M. R. K. Singh. 2003. Stability analysis in mungbean [*Vigna radiata* L. Wilczek]. Res. on Crops. 4: 97-103.

Paterson, A.H., Y. Saranga, M. Menz, C.X. Jiang and R.J. Wright. 2003. QTL analysis of genotype × environment interactions affecting cotton fiber quality. Theorl. Appl. Genet. 106: 384-396.

Sharma,J. K and L. Swarn. 2002. Stability analysis in sweat buckwheat. Crop Res. 23: 12-14.

Simmonds, N.W. 1991. Selection for local adaptation in a plant breeding programme. Theol. Appl. Genet. 82: 363-367.

Singh, R.K. and B.D. Chaudhary. 1985. Biometrical Method in Quantitative Genetic Analysis (rev.Ed.) Kalyani Publishers. New Delhi. India pp. 252-269.

(Received 1 August 2007 ; Accepted 31 August 2007)