한작지(Korean J. Crop Sci.), 53(3): 297~302(2008)

Genotype x Environment Interaction for Yield in Sesame (*Sesamum indicum* L.)

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ABSTRACT Application of genotype by environment (G × E) interaction would be used for identifying optimum test condition of the varietal adaptation in the establishment of breeding purpose. Yield and yield components were used to perform additive main effect and multiplicative interaction (AMMI) analysis. Significant difference for G × E interaction were observed for all variable examined. For yield, 0.18 of total sum of squares corresponded to G × E interaction. Correlation analysis was carried out between genotypic scores of the first interaction principal component axis (IPCA 1) for agronomic characters. Significant correlations were observed between IPCA 1 for yield and capsule bearing stem length (CBSL), number of capsule per plant (NOC). The biplot of grain yield means for IPCA1 which accounted for 34% of the variation in total treatment sums of squares showed different reaction according to G × E interaction, genotypes and environments. Taegu showed relatively lower positive IPCA1 scores, and it also showed smaller coefficient variation of yield mean where it is recommendable as a optimal site for the sesame cultivar adaptation and evaluation trial. In case of variables, Yangbaek and M1 showed relatively lower IPCA1 scores, but the score direction showed opposite each other on the graph. Ansan, Miryang1, Miryang4, and Miryang6 seemed to be similar group in view of yield response against IPCA1 scores. These results will be helpful to select experimental site for sesame in Korea to minimize G × E interaction for the selection of promising genotype with higher stability.

Keywords : sesame, AMMI, G × E interaction, IPCA1 score

Sesame (*Sesamum indicum*) is very important annual crops in Korea, where about 15,500 metric tons of sesame seeds were produced at the 31,000 ha cultivation areas in 2006. But the degree of self-sufficiency in Korea was about 23%. To raise domestic self-sufficiency of sesame, new sesame varieties with high yield potential, quality and yield stability should be developed. The origin of sesame is savanna tropical areas, and it's productivity was mainly determined by meteorological factors such as temperature, rainfall and amount of solar radiation. During the sesame cultivation period in Korea where it is usually from middle of May to early of September, heavy rain and typhoon mostly affect or determine sesame productivity. Therefore, it is very important to analyze regional experiment for sesame to minimize G × E interaction for the optimum selection or evaluation sites for the sesame breeding in Korea. Comparisons of varieties at different environments may results in high genotype by environment (G × E) interaction (Fehr, 1987). For more detailed analysis of the interactions, the additive main effect and multiplicative interaction (AMMI) model has been found to be an effective tool (Allard and Bradshaw, 1964). AMMI is especially effective where the assumption of linearity of the response of genotype to a change in the environment is not fulfilled (Zobel *et al*., 1988; Yan and Hurt, 1998) and which is required in stability analysis techniques (Eberhart and Russell, 1966). The AMMI model dose not require this assumption. It usually separates the interaction part of the multiplicative components into the additive main effects by principal component analysis. The present experiment aimed to determine the genotypic and environmental factors relating to G × E interaction and quantify the G × E interaction effects on yield in terms of different sesame cultivation environments to develop new approach for the breeding of new sesame varieties with higher stability in Korea.

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<Received March 28, 2008>

MATERIALS AND METHODS

Plant materials and experimental environments

This experiment was conducted at Suwon, Cheongwon, Yeasan, Iksan, Taegu and Jinju areas from 2004 to 2006. Total ten sesame varieties, Yangbaek, Ansan, Yanghuk, Suwon195, Kyeongbuk2, Miryang1, Miryang2, Miryang4, Miryang5 and Miryang6 were used for this experiment. The experimental plot was about 12 m^2. A black polyethylene film with 30×10 cm spacing holes were mulched and sown the seed. Finally, the young seedlings were thinned to make one plant per hole. Basic fertilizer ($N\text{-}P_2O_5\text{-}K_2O$ = 8-4-9) was applied as the basal condition. Soil characteristics of experimental sites were analyzed in three years (Table 1). Generally, pH and O.M. (%) were ranged 4.5~5.5, 0.53~2.16 respectively, and Av. P_2O_5 was 11~247 ppm. Among the exchangeable cation, Ca was ranged 1.18~4.50, Mg 0.70~2.28, Na 0.10~3.003 and K 0.18~0.57. C.E.C (mg/100 g) and degree of base saturation were 6.2~11.8, 35.7~105.5% respectively.

Table 2 showed yield related agronomic characters of ten sesame cultivars at the experimental sites from 2004 to 2006. Flowering date and maturing date were not shown much difference except Kyeongbuk2 which was 5~7 days late than those other materials. Yangbaek and Suwon195 showed higher capsule bearing stem length, number of capsule per plant respectively. In case of grain yield comparison, Mir yang1 showed highest mean yield as 102 kg per 10 are, but Yanghuk and Suwon195 recorded about 87 kg per 10 are which was lowest among ten materials.

In comparison of grain yield, Miryang1 showed higher average yield across the seven environment (Table 3). And

Table 1. Average soil characteristics at the seven different experimental sites.

Site	pH	Organic Matter (%)	C.E.C (me/100 g)	Exch. cation (me/100 g)				Deg. of base saturation (%)	Avail. phosphate (ppm)
				Ca	Mg	Na	K		
Yeasan	4.5	0.53	6.2	1.18	0.70	0.10	0.18	35.7	11
Suwon	5.1	2.16	11.8	2.70	1.07	0.23	0.52	38.5	247
Cheongwon	4.5	1.08	6.5	2.40	1.20	0.08	0.50	64.3	196
Iksan	4.7	1.86	11.6	2.37	1.15	0.15	0.57	36.5	143
Taegu	4.9	0.91	8.1	4.25	2.28	0.18	0.18	85.1	35
Jinju	5.2	1.23	7.0	3.75	1.15	0.18	0.40	78.3	167
Miryang	5.5	1.36	9.2	4.50	2.03	3.00	0.18	105.5	52

Table 2. Yield related agronomic characters of ten sesame varieties across seven experimental sites in 2004~2006

Variety	Flowering date	Maturity date	Stem length (cm)	Capsule bearing stem length (cm)	No. of capsule per plant	1000 seeds wt (g)	Yields (kg/10a)
Yangbaek	June 3	Oct.19	132	91	80	2.63	94
Ansan	June 2	Oct.20	130	82	67	2.70	88
Yanghuk	June 3	Oct.25	128	80	74	2.77	87
Suwon195	June 2	Oct.22	137	82	88	2.56	87
Kyeongbuk2	June 7	Oct.29	155	90	91	2.63	99
Miryang1	June 2	Oct.21	140	89	76	2.80	102
Miryang2	June 2	Oct.20	138	90	78	2.74	99
Miryang4	June 2	Oct.20	135	86	80	2.68	97
Miryang5	June 3	Oct.21	129	82	75	2.58	97
Miryang6	June 2	Oct.21	133	81	67	2.95	99
S. D.	0.1	0.1	7.8	4.3	7.7	0.2	43.1

Table 3. Mean yield (kg/10a) of ten sesame cultivars across seven environments

	Miryang	Suwon	Cheongwon	Yeasan	Iksan	Taegu	Jinju	Mean	C. V.
Yangbaek	105	79	84	99	65	106	120	94	18.6
Ansan	88	64	85	100	67	99	106	87	17.4
Yanghuk	97	82	79	93	57	94	100	86	16.1
Suwon195	107	74	86	83	59	97	100	86	17.7
Kyeongbuk2	97	81	100	86	82	115	129	98	16.9
Miryang1	119	79	99	106	70	107	130	102	19.3
Miryang2	123	81	90	94	57	110	133	98	24.5
Miryang4	104	83	89	102	61	106	129	96	20.5
Miryang5	115	102	77	105	68	104	108	97	16.7
Miryang6	113	86	82	97	71	105	134	98	20.0
Mean	107	81	87	97	66	105	119	94	
C. V.	9.7	11.1	8.4	7.5	11.2	5.7	11.1		
S. D.	10.9	9.5	7.7	7.6	7.7	6.2	14.0		

Jinju and Miryang areas showed relatively favored environments for the sesame cultivation in view of mean yield.

Methods of statistical analysis and those application

Yield and its components were analyzed by means of the AMMI model (Gauch 1992). Usually, general AMMI model was expressed by $Y_{ij} = \mu + g_i + e_j + \Sigma\lambda_k\gamma_{ik}\delta_{jk} + \varepsilon_{ij}$, where Y_{ij} is the yield of *i*-th genotype in the *j-th* environment; μ is the grand mean; g_i and e_j are the deviations of genotype and environment from the grand mean, respectively. λ_k is the eigenvalue of the principal component analysis (PCA) for axis *k*; γ_{ik} and δ_{jk} are the genotype and environment principal components scores for axis *k*; *N* is the number of principal components in the AMMI model; ε_{ij} is the residual term. Genotype and environment PCA scores are expressed as unit vector times the square root of λ_k (genotype PCA score = λ_k δ_{ik}, environment PCA score = λ_k δ_{ik}, (Zobel *et al.*, 1988)). To interpret G × E interaction, correlation analysis was conducted between genotypic and environmental scores of the first and second interaction principal component axes (IPCA1 and IPCA2) from the AMMI model.

RESULTS AND DISCUSSION

Analysis of variance of genotypes, environments and G x E for grain yield

AMMI analysis of variance indicated that three multiplicative terms were significant ($P < 0.05$). These multiplicative terms account for 34.1, 20.4, and 14.8% of sum of sqaures of the genotype × environment interaction. These terms accounts for a total of 69.3% of the interaction with 55.6% for the corresponding degree of freedom. The AMMI model partitioned G × E interaction effects into successively specific patterns. Partitioning of G × E indicates that AMMI-4 model describes the G × E patterns for yield by the first four interaction principal component analysis (IPCA) scores using Gollb's *F*-test (Table 4). Of the total variations, about 18% is due to G × E interaction effects, and 82% is due to genotype and environmental effects which are explained by additive main effect.

Biplot of interaction principal components between genotypes and environments

In Table 4, the large sum of squares for IPCA1 compared to those of IPCA2 would be justify the use of AMMI1 to visualize the mean yield of the genotypes and environments, and G × E interaction for all possible genotype-environment combination. The biplot enabled a visual comparison of the locations and genotypes, and their relationships. The vertex genotypes were the most responsive to the closest environment and represented either the best or the poorest performers across the environments, appearing farthest from the biplot origin (Yan *et al.*, 2000). Day after flowering (DAF) and number of capsule per plant (NOC) showed the main factor of G × E interaction for yield with negative and positive correlation respectively (Table 5). Negative interactions are those that negatively affect the most or optimal expression of genotypic characteristics across different environments. In table 4, days after maturity (DAF), capsule bearing stem length (CBSL) and number of capsule per plant (NOC) showed positive correlation to the genotypic IPCA 1 scores, whereas 1,000-seed weight (TSW) showed negative correlation.

The biplot of grain yield means for IPCA1 showed different reaction according to G × E interaction, genotypes and environments (Figure 1). The biplot accounts for 34% of the variation in total treatment sums of squares (Table 3). The main effects and each score are shown in the graph and used to predict yield of genotypes in each environment.

Higher IPCA scores both with positive and negative attribute to higher G × E interaction. In Figure 1, Suwon and Cheongwon showed larger positive and negative IPCA1 scores indicating that higher portion of G × E interaction was affected to the expression of sesame yield in those areas. Otherwise, Taegu showed relatively lower positive IPCA1 scores, and it also showed smaller coefficient variation of yield mean (Table 3) indicating relatively lower G × E interaction and environmental effect at the AMMI analysis

Table 4. Analysis of variance with interactive model (a) and partitioning of interaction with AMMI (b)

a

Source of variation	df	Sum of Squares	Efficiency (%)	Mean Squares	*F*-test
Total	209	167790.03	100.0		
Genotype	9	6233.57	3.0	692.62	**
Environment	20	130968.00	78.8	4548.39	**
G × E	180	30588.46	18.2	169.94	**

b

Partitioning of interaction with AMMI

Source of variation	df	Sum of Squares	Efficiency (%)	Mean Squares	*F*-test
G × E	180	30588.46	100.0	169.94	
IPCA1	28	10408.50	34.1	371.73	**
IPCA2	26	6213.00	20.4	238.96	**
IPCA3	24	4520.15	14.8	188.34	*
IPCA4	22	2741.95	8.8	124.63	
Residual	80	6704.86		83.81	

**, *Significant at 0.05 and 0.01 probability levels.

Table 5. Pearson correlation coefficients between first interaction principal components axis (IPCA 1) scores for the genotypic variables and agronomic characteristics across seven environments

	Genotypic IPCA 1 scores							
	DAF	DAM	STL	CBL	NOC	TSW	LW	Yield
DAF	0.81**	0.68*	0.38	0.25	0.34	0.66*	0.36	**-0.45***
DAM	0.19	0.43	0.71**	0.74**	0.64*	0.65*	0.39	-0.29
STL	0.55*	0.86**	0.66*	0.28	0.62*	0.22	0.24	-0.14
CBL	0.15	0.40	0.20	-0.43	0.23	-0.21	0.33	**0.54***
NOC	0.48*	0.59*	0.89**	0.33	0.43	0.33	0.54*	**0.60***
TSW	-0.06	-0.18	-0.55*	-0.27	-0.07	0.08	-0.12	-0.06
LW	0.11	0.23	0.31	-0.21	0.09	-0.55*	-0.09	0.08
Yield	0.43	0.27	-0.17	-0.56*	0.15	0.26	0.48	0.67*

**,*Significant at the 1%, 5% probability level respectively.

of variance. Therefore it is recommendable to Taegu as a optimal site for the sesame cultivar adaptation and evaluation trial. In case of variables, Yangbaek and Miryang1 showed relatively lower IPCA1 scores, but the response was different; one is negative score, the other is positive score. Variables could be grouped as the responses of IPCA1 scores. Ansan, Miryang1, Miryang4, and Miryang6 seemed to be similar group in view of yield response against IPCA1 scores.

The biplot of Figure 2 with IPCA1 against IPCA2 shows relative magnitude and G × E direction according to the interaction effects of genotypes and environments. Response of mean yield of environments at the biplot distribution is more wide spread than those of genotypes. Generally, genotypes and environments with smaller G × E effects are located

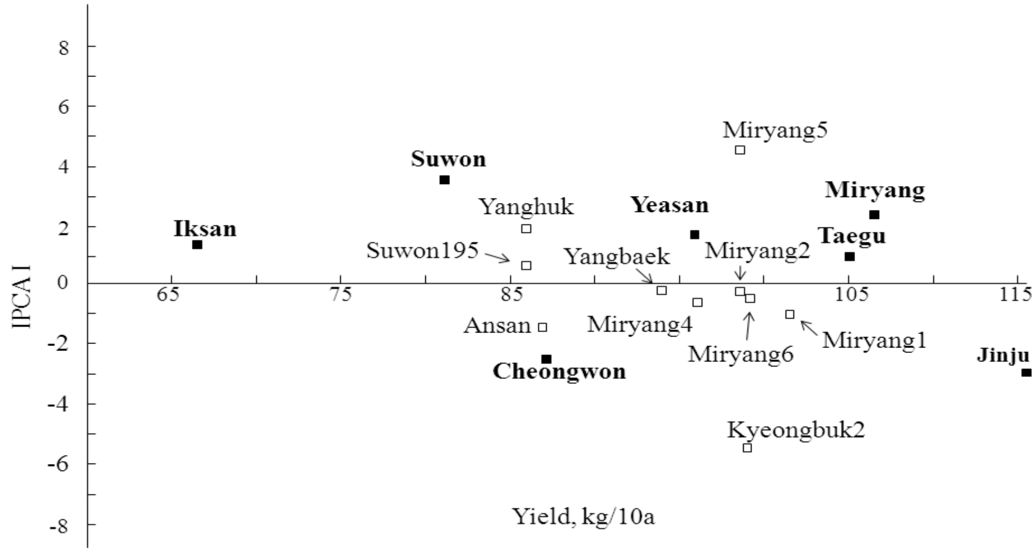

Fig. 1. Biplot of yield means and the first interaction principal components axis (IPCA1) scores of ten sesame genotypes and seven environments (bold letter). Genotypes are indicated with open squares and environments with closed squares.

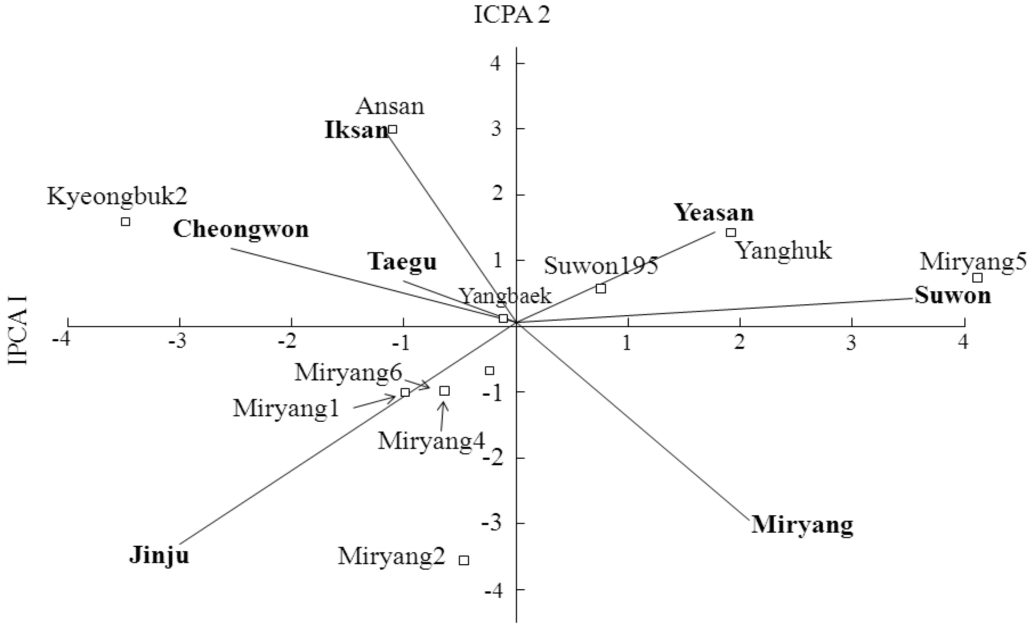

Fig. 2. Biplot of the yield means and the first interaction principal components axis (IPCA1) scores and the second interaction principal components axis (IPCA2) scores of ten sesame genotypes and seven environments.

at the center of both axes. In Figure 2, Jinju, Miryang and Suwon showed relatively longer vector length than those of Taegu and Yeasan indicating smaller G × E effects.

Those location-dependent differences may be attributed to environmental factors, such as temperature, rainfall, altitude and soil characteristics of experimental places. Genotypes and environments marking same or opposite horizontal/vertical direction mean to have same or opposite G × E patterns. According to the biplot analysis, Iksan, Cheongwon and Taegu showed similar G × E interaction direction, but Jinju and Miryang showed different interaction reaction. Yanghuk, Kyeongbuk2 and Miryang2 showed different directions on the plot suggesting relatively different G × E effects or magnitudes according to the locations. The biplots displayed variable patterns of genotypes, environments and their interactions. Consequently, it is possible to use this information for the optimal site selection (i.e. Taegu) with reliable stability or for the variety selection with high stability. An understanding of G × E interaction can be applied to identify environmental factors that can be manipulated for the promising variety selection in crops breeding schemes (Yan and Hunt 2001; Laurentin *et al*., 2006).

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