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Estimation of combining ability for grain yield and its components in 4 x 4 diallel cross of Maize (*Zea mays* L.)

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Abstract
Combining ability effects were estimated for maize (*Zea mays* L.) grain yield and six related agronomic traits in 4 x 4 diallel analysis. Mean squares due to genotypes and specific combining ability effects for all traits except number of ears per plant were highly significant. Mean squares due to general combining ability effects were highly significant for ear height and number of grain rows per ear and significant for plant height and 100-grain weight, while these were non-significant for number of ears per plant, number of grains per row and grain yield per hectare. Variances due to specific combining ability were greater and more important for all characters except number of rows per ear. It indicated the presence of non-additive type of gene action. The inbred line USSR-3135 proved to be the best general combiner for number of rows per ear (0.352), number of grains per row (0.537) and grain yield per unit area (0.343), whereas the inbred line IMAN-I was good general combiner for plant height (0.055), inbred line A-637 was good general combiner for ear height and the inbred line ASE-304 was good combiner for 100-grain weight. A cross USSR-3135 x A-637 showed the best specific combining ability effect (3.253) for grain yield.

Introduction
Maize (*Zea mays* L.), the sole cultivated member of the genus *Zea* and is a well known staple food and feed crop in three districts of Diamer, Gilgit and Ghizer of Northern Areas of Pakistan. The average per hectare grain yield of one metric tone is the lowest in the world. Low production in Northern Areas as well as in Pakistan is mainly due to the low yielding open- pollinated varieties, which are loosing their stabilities in succeeding generations, whereas the high average grain yields of 2.5 to 4.5 metric tonnes per hectare in maize growing countries like USA, Mexico, Canada, Denmark, Span, France, Italy etc., are due to the development and introduction of hybrid maize coupled with better cultural practices. The prevailing critical grain and fodder production situation of the area provides an immense opportunity of success to those who are involved in enhancement of productivity of this crop through introduction of improved cultivars and better production practices. Hybrid maize has potential to stabilize the food and feed situation in the area and can help to solve the problem of food and feed shortage which is becoming more and more serious due to ever increasing population and demand for animal feed.

In order to select inbred lines of maize with high yielding potentiality, a plant breeder has to deal with hundreds of crosses before he can pick-up the desired inbred lines for better combinations. Keeping in view the available resources, a plant breeder is always forced to look for such techniques as to help him in selecting the desirable parental lines for hybridization purposes and screening his material in early generations. The diallel cross technique as developed by Sprague and Tatum (1982) and Griffing (1956) provided information on gene action and combining ability of parental lines in cross combinations right in F_1 generation. According to them, the general combining ability effects were due to additive type of gene action, whereas specific combining ability effects were due to non-additive type of gene action. Many workers like Pakudin (1977), Piovarci (1975) and Saleem *et al.* (1978) have reported high specific combining ability effects for grain yield and yield components.

Materials and Methods
Twelve exotic and local maize inbred lines, viz., WM-13R, B-34, USSR-3135, USSR-40, W-82-1, IMAN-I, A-637, A-639, ASE-204, N-20, OH-14A and K-55 were introduced from the department of plant breeding and genetics, University of Agriculture, Faisalabad and evaluated through top-crosses with an open-pollinated maize variety Azam. On the basis of exceptional ability to combine, four inbred lines, viz., IMAN-I, USSR-3135, A-637, and ASE-204 were selected for further hybridization program. These four lines were crossed in all possible combinations (excluding reciprocals) at Agriculture Farm Chilas Diamer, Northern areas, Pakistan during summer season, 1988 and the seed was maintained. In 1996 the seed of these four inbred lines alongwith their $6F_1$'s was planted in four rows of three meters length spaced 60 cm apart in a randomized complete block design in three replicates. Two seeds were placed in each hill of 25 cm apart within a row. A few days after germination all the treatments were thinned to a single plant in each hill to get a uniform stand.

A uniform doses of 150 and 100 kg ha^{-1} N and P_2O_5 was applied to all treatments, respectively. All other cultural practices were carried-out according to the standard commercial recommendations for maize. The previous crop was wheat and the soil was sandy-loam and calcarious type. Ten guarded plants from each plot were randomly selected to record the data on plant height (PH), ear height (EH), number of ears per plant (EP), number of rows per ear (RE) and number of grains per row (GR). Three random samples from the grains of each plot were taken to record the data on 100-grain weight. Two central rows were harvested to record grain yield from each plot. The data were analyzed according to the analyses of variance techniques as suggested by Steel and Torrie (1980) and the significant differences among the means of various genotypes were tested by DMR test at 5 per cent level of significance. The combining ability analyses were done by method 2, model 2 of Griffing (1956)

Results and Discussion

The analysis of variance (Table 1) showed highly significant differences among genotypes for all characters except number of ears per plant. This indicated the presence of an adequate genetic variability which can be exploited in different crossing programmed. The variance attributable to specific combining ability effects was highly significant for all characters except number of ears per plant, whereas the variance attributable to general combining ability effects was also highly significant for traits like ear height and number of rows per ear, while it was significant for plant height, 100-grain weight and non-significant for number of grains per row and grain yield per hectare. The mean data for various agronomic traits are given in Table 2. The average plant height (cm), ear height (cm), number of ears per plant, number of rows per ear, number of grains per row, 100-grain weight (g) and grain yield (tonnes ha $^{-1}$) ranged from 1.67 to 2.22, 0.69 to 1.03, 1.00 to 1.25, 12.80 to 16.13, 22.49 to 33.97, 16.56 to 25.34 and 0.673 to 8.000, respectively. The genotypes IMAN-1 x A-637, USSR-3135 x A-637, USSR-3135 x ASE-204, A-637 x ASE-204 and USSR-3135 x A-637 were superior for plant height and ear height, number of rows per ear, number of grains per row, 100-grain weight and grain yield, respectively.

The estimates of components of variances due to general and specific combining ability effects for grain yield and its components are presented in Table 3. The estimates revealed that the magnitude of specific combining ability variance was higher than general combining ability variances for all the agronomic traits except number of rows per ear, where the magnitude of general combining ability variances was higher than specific combining ability. The specific combining ability variance for number of grains per row, 100-grain weight and grain yield was the greatest with the values of 19.767, 14.320 and 15.105 per cent, respectively. The general combining ability variances ranged from 13.07 to 36.76 per cent for grain yield and number of grain rows per ear, respectively, whereas the percentage for specific combining ability variances ranged from 60.89 to 85.31 for number of grain rows per ear and grain yield, respectively. The estimates of components of variances due to general and specific combining ability indicated the predominance of non-additive gene action.

In a population of un-selected lines for combining ability genes with additive effects (GCA) are more important and producing greater effects than the genes with dominance or epistatic effects. However, in the previously selected material, the genes with dominance and epistatic effects were more important than genes with additive effects because the previously eliminated lines performed similarly unlike the original population. Since differences in additive effects were largely eliminated, dominance and epistatic effects became relatively more important. Similar results were reported by Huang *et al.* (1983), Inoue (1984), Javed *et al.* (1988) and Sprague and Tatum (1982). The data given in Table 4 showed that inbred line USSR-3135 had better general combining ability with the values of 0.352, 0.537 and 0.342 for number of rows per ear, number of grains per row and grain yield, respectively. Genotypes IMAN-I, A-637 and ASE-204 showed better general combining ability for plant height, ear height, number of grains per row and 100-grain weight, respectively. But USSR-3135 was poor combiner with negative general combining ability values (-0.047, -0.012 and 0.101) for plant height, ear height and 100-grain weight, respectively. Similarly, IMAN-I, A-637 and ASE-204 were also poor combiners for other agronomic traits mostly with negative general combining ability values. The inbred line USSR-3135 gave the highest general combining ability values for number of rows per ear, number of grains per row and gr

Table 1. Mean squares of the diallel analyses for the maize yield and other agronomic traits

Source of variation	df	Mean squares						
		PH	EH	RE	GR	100-grain	Yield	EP
Blocks	2	0.044*	0.001^{ns}	1.552^{ns}	17.450^{ns}	0.063^{ns}	0.003^{ns}	0.056
Genotypes	9	0.096**	0.034**	3.428**	45.424**	28.136**	30.854**	0.061
Error	18	0.013	0.006	0.614	5.924	2.084	0.429	0.045
GCA	3	0.016*	0.422**	12.639**	2.502^{ns}	2.631*	0.394^{ns}	0.003
SCA	6	0.040**	0.214**	4.567**	21.453**	14.934**	15.234**	0.027
Error	18	0.004	0.002	0.205	1.975	0.693	0.143	0.015

* = significant at 5%, ** = significant at 1% probability level and ns = non-significant

Table 2: Mean values for 4 maize inbred lines and their single crosses for grain yield and six agronomic traits in maize

Genotypes	Yield (t/ha)	100-grain Wt.(g)	GR	RE	EP	EH (cm)	PH (cm)
USSR-3135 X A-637	8.000	24.22	27.00	16.13	1.25	0.92	2.00
USSR-3135 X ASE-204	7.467	23.89	33.97	15.44	1.42	0.87	2.01
IMAN-I X USSR-3135	7.127	24.33	30.47	15.50	1.17	0.83	2.06
IMAN-I X ASE-204	6.880	20.22	31.07	14.63	1.08	1.03	2.12
IMAN-I X A-637	6.853	21.00	26.23	15.13	1.08	0.82	2.22
A-637 X ASE-204	5.507	25.34	27.43	14.30	1.25	0.92	2.08
USSR-3135 X USSR-3135	1.071	16.56	23.22	13.80	1.00	0.74	1.72
IMAN-I X IMAN-I	1.023	18.67	22.49	14.17	1.00	0.69	1.86
A-637 X A-637	0.767	18.33	24.72	12.80	1.00	0.80	1.84
ASE-204 X ASE-204	0.673	19.22	22.70	13.17	1.00	0.71	1.67
Array total							
1	21.883	84.22	110.266	59.43	4.33	3.37	8.26
2	23.665	89.00	114.651	60.87	4.84	3.39	7.79
3	21.127	88.89	105.377	58.36	4.58	3.46	8.14
4	20.527	88.67	105.170	57.54	4.75	3.53	7.88
Grant total	45.368	211.23	269.297	145.13	11.25	8.33	19.58
Diagonal value	3.534	72.78	93.130	53.93	4.00	2.94	7.09

GR = Number of grains per row RE = Number of grain rows per ear EP = Number of ears per plant
EH = Ear height (cm) PH = Plant height (cm)

Table 3: Estimates of components of variance due to general and specific combining ability for grain yield and its components in a 4 x 4 diallel cross of maize

Source of variance	Variance						
	PH	EH	EP	RE	GR	100-grain	Yield
GCA	-0.004	0.035	-	2.868	-3.159	-2.046	-2.473
age	-9.090	14.060	-	36.760	-12.840	-12.040	-13.070
SCA	0.036	0.212	-	-4.750	19.767	14.329	15.105
%age	31.320	85.140	-	60.890	79.230	84.200	85.310
Error	0.004	0.002	-	0.184	1.777	0.626	0.129
%age	9.090	0.820	-	2.360	7.220	3.680	0.730

Table 4: Estimation of general combining ability effects for yield and its components in a 4 x 4 diallel cross in maize

Parents	PH	EH	RE	GR	100-grain	Yield
IMAN-I	0.055	0.185	0.181	-0.309	-0.505	0.037
USSR-3135	-0.047	-0.012	0.352	0.537	-0.101	0.342
A-637	0.032	0.015	0.042	-0.759	0.269	-0.132
ASE-204	-0.040	0.012	-0.309	0.537	0.288	-0.247
SE gi-gj	0.037	0.026	0.248	0.770	0.456	0.207

Table 5: Estimates of specific combining ability effects for yield, yield components and agronomic traits in a 4 x 4 diallel cross of maize

Crosses	PH	EH	RE	GR	100-GWT	Yield
USSR-3135 X A-637	0.056	0.022	1.243	6.715	2.933	3.253
USSR-3135 X ASE-204	0.069	0.032	0.543	13.688	2.047	2.133
IMAN-I X USSR-3135	0.091	0.192	0.454	11.675	3.818	2.212
IMAN-I X ASE-204	0.151	0.392	-0.413	12.271	-0.295	1.965
IMAN-I X A-637	0.257	0.182	0.137	7.431	0.485	1.938
A-637 X ASE-204	0.132	0.058	0.063	10.236	3.658	1.350
SE (sij-sik)	0.082	0.058	0.554	1.721	1.021	0.464
SE (sij-ski)	0.073	0.052	0.495	1.539	0.913	0.415

yield. Therefore, this line can be used extensively for the development of desirable genotypes for these characters in future.

The data in Table 5 on specific combining ability effects for various traits expressed that the cross between USSR-3135 x A-637 had the best specific combining ability for number of rows per ear (1.243) and grain yield (3.253). The genotype USSR-3135 x ASE-204 indicated higher specific combining ability (13.688) for number of grains per row followed by the genotype IMAN-I x ASE-204 with a value of 12.271. The cross IMAN-I x USSR-3135 was the best specific combiner for 100-grain weight (3.818) followed by the cross A-637 x ASE-204 (3.658). The crosses IMAN-I x ASE-204 and IMAN-I x A-637 were the best specific combiners with the values of 0.352 and 0.237 for ear height and plant height, respectively. It was concluded from the results obtained that genotype USSR-3135 had better general combining ability for number of rows per ear, number of grains per row and grain yield. It also expressed better specific combining ability for grain yield, number of rows per ear, number of grains per row and 100-grain weight. Therefore, it can be used in hybridization program for obtaining desirable combinations for increased grain yield per unit area.

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