INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2004/06–5–856–859
http://www.ijab.org

General and Specific Combining Ability Studies in Maize Diallel Crosses

SAAD IMRAN MALIK[1], HAQ NAWAZ MALIK†, NASIR MAHMOOD MINHAS AND MUHAMMAD MUNIR
Department of Plant Breeding & Genetics, University of Arid Agriculture, Rawalpindi–Pakistan
†Maize, Sorghum and Millet Programme, NARC, Islamabad–Pakistan
[1]Corresponding author's e-mail: saad_uaar@yahoo.com

ABSTRACT

Information about combining ability is important for making breeding strategies. A nine parent diallel excluding reciprocals was formed for the inbreds developed by the Maize Programme at NARC, Islamabad. These inbreds were derived from material from temperate, subtropical and tropical ecologies and their combining ability effects were estimated for 11 biometric traits. GCA effects were highly significant for all the traits under study, but SCA effects were less significant in certain cases suggesting predominance of additive genes. High GCA effects for grain yield were observed in the temperate material i.e. QPM-1 (0.168), QPM-3 (0.169) and QPM-5 (0.485), while SCA effects were remarkable for hybrids QPM-3 × NCML-1078 (0.890), NCML-1071 × NCML-1084 (0.878) and NCML-1082 × NCML-1083 (0.831). Temperate material also gave high GCA effects for striking characters contributing towards high grain yield i.e. plant and ear heights, leaf area, ears plant^{-1}, ear weight and kernels row^{-1}. Tropical inbreds gave eminent GCA effects for days to pollen shedding, ear weight and grain moisture at harvest. Considering its negative GCA and SCA effects for days to pollen shedding, subtropical material was marked as a valuable source for inducing earliness.

Key Words: Maize; *Zea mays;* Diallel; Combining ability

INTRODUCTION

Maize (*Zea mays* L.) is the world's most widely grown cereal and is the primary staple food in many developing countries (Morris *et al*., 1999). The concept of general combining ability (GCA) and specific combining ability (SCA) was introduced by Sprague and Tatum (1942) and its mathematical modeling was set about by Griffing (1956) in his classical paper in conjunction with the diallel crosses. The value of any population depends on its potential *per se* and its combining ability in crosses (Vacaro *et al*., 2002). The usefulness of these concepts for the characterization of an inbred in crosses have been increasingly popular among the maize breeders since the last few decades.

Maize hybrids are cultivated on only a limited area in the developing countries in spite of their higher yield potential (Vasal *et al*., 1994). Paterniani (1990) discussed several characteristics of temperate and tropical maize production and suggested that the problems facing maize cultivation in the tropics are more numerous and are of greater magnitude and more challenging than in temperate areas. A series of combining ability studies have been made by many workers from the International Maize and Wheat Improvement Center (CIMMYT) to establish heterotic patterns among several maize populations and gene pools, and to maximize their yield for hybrid development (Beck *et al*., 1990, 1991; Crossa *et al*., 1990; Vasal *et al*., 1992). Likewise, the variances of general and specific combining ability are related to the type of gene action involved. Variance for GCA includes additive portion while that of SCA includes nonadditive portion of total variance arising largely from dominance and epistatic deviations (Rojas & Sprague, 1952).

Diallel crosses have been widely used in genetic research to investigate the inheritance of important traits among a set of genotypes. These were devised, specifically, to investigate the combining ability of the parental lines for the purpose of identification of superior parents for use in hybrid development programmes. Analysis of diallel data is usually conducted according to the methods of Griffing (1956) which partition the total variation of diallel data into GCA of the parents and SCA of the crosses (Yan & Hunt, 2002). A diallel is simple to manipulate in maize and supplies important information about the studied populations for various genetic parameters (Vacaro *et al*., 2002). The analysis is also useful for the evaluation of populations *per se*.

The objective of this study was to evaluate the performance of nine maize inbred lines derived from the material of temperate, subtropical and tropical origins. These promising lines were never appeared to be tested before for their breeding potential *per se* in specific combinations (SCA) and their overall performance in crosses (GCA). These lines would be a valuable source of germplasm to enhance hybrid grain yield in Pakistan.

MATERIALS AND METHODS

The experimental material comprised of nine inbred lines of maize viz. QPM-1, QPM-3 and QPM-5 from temperate, NCML-1061, NCML-1071 and NCML-1078 from subtropical, and NCML-1082, NCML-1083 and NCML-1084 from tropical origins. These lines were crossed in the spring of the year 2002, in a diallel mating design without reciprocals to form 36 F_1 hybrids. Each ear was obtained by cross fertilization to one tassel only and no tassel was used to pollinate more than two ear shoots. The ears were harvested, dried and shelled manually. These were kept in the controlled environment for use in the trials in the next growing season.

All the F_1 hybrids along with their parental lines were grown in the following growing season. Trials were irrigated throughout the growing season and cultural operations, fertilization, and weed control were accomplished according to normal field practices. Hills were overplanted and thinned after emergence for a final plant density of about 56,000 plants ha^{-1}. The experiment was replicated twice in a randomized complete block design. The experimental unit was one row for each entry, 5 m long and 75 cm apart, with plant to plant distance of 25 cm.

Data for days to pollen shedding, plant height (from soil to the lowest tassel branch), ear height (from soil to the leaf subtending the ear), leaf area (according to Payne *et al*., 1991) and number of ears plant^{-1} were taken before harvest. After all the entries gained physiological maturity, the ears were harvested, husked and weighed. Data for ear weight, grain moisture at harvest, number of kernel rows ear^{-1}, number of kernels row^{-1} and grain yield plot^{-1} were taken after harvest. 100-kernel weight was taken after ears were dried for about two months to a constant moisture level of 15%.

Analyses of variance were completed for all the traits under study using plot mean data. The hybrids and hybrid interaction sum of squares were partitioned into general combining ability (GCA) and specific combining ability (SCA) effects according to Griffing (1956) Method-II, (Fixed Model) with the diallel analysis package MSTAT-C (Version 2.10). Due to space limitations only selected parameters will be discussed in detail.

The analysis was based on the model by Griffing (1956) as:

$$x_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc}\sum_k \sum_l e_{ijkl}$$

where x_{ij} is the mean of $i \times j^{th}$ genotype over k and l, μ is the population mean, g_i is the GCA effect, s_{ij} is the SCA effect such that $s_{ij} = s_{ji}$, and e_{ijkl} is the effect peculiar to the $ijkl^{th}$ observation.

i, j = 1, 2, p
k = 1, 2, b
l = 1, 2, c

RESULTS

Analyses of variance revealed that mean square values for GCA were highly significant ($P \leq 0.01$) for all the traits studied (Table I). Means squares for SCA were also highly significant for most of the traits under study. Exceptions were ear height and number of ears plant^{-1} ($P \leq 0.05$), while for grain moisture at harvest and number of kernels row^{-1},

Table I. Observed mean squares from general combining ability (GCA) and specific combining ability (SCA) analyses based on Griffing's Method II, (fixed effects) for different characters

Source	Degrees of freedom	Days to pollen shedding	Plant height (cm)	Ear height (cm)	Leaf area (cm^2)	Ears plant^{-1}	Ear weight (kg)	Grain moisture at harvest (%)	Kernel rows ear^{-1}	Kernels row^{-1}	100-kernel weight (g)	Grain yield (kg plot^{-1})
GCA	8	165.08**	954.34**	369.04**	11228.70**	0.17**	0.005**	59.89**	4.93**	59.44**	23.28**	1.74**
SCA	36	32.06**	390.16**	151.74*	5547.03**	0.03*	0.002**	11.34	1.95	33.62**	18.00**	0.59**
Error	44	6.71	104.15	86.26	2512.15	0.02	0.001	8.35	1.34	5.71	6.67	0.22

**Significant at 1% and, *Significant at 5% probability level.

Table II. Estimates of general combining ability (GCA) effects of each parental line for different characters

Parents	Days to pollen shedding	Plant height	Ear height	Leaf area	Ears plant^{-1}	Ear weight	Grain moisture at harvest	Kernel rows ear^{-1}	Kernels row^{-1}	100-kernel weight	Grain yield
QPM-1	-0.929	7.015	4.990	20.254	0.095	-0.005	-0.678	-0.278	1.364	0.153	0.168
QPM-3	0.662	3.061	3.263	18.864	0.095	0.002	1.481	-0.369	1.545	-1.024	0.169
QPM-5	1.298	3.924	4.035	41.322	-0.035	0.031	-0.841	0.131	1.545	0.989	0.485
NCML-1061	-2.429	-11.85	-6.374	-30.130	-0.057	-0.020	-0.623	-0.596	-2.636	0.848	-0.483
NCML-1071	-3.747	-1.576	0.035	-14.350	0.089	-0.013	-2.637	0.268	-0.182	1.662	0.065
NCML-1078	-2.566	3.470	0.763	-4.683	0.630	-0.004	-0.946	0.313	0.045	-0.938	0.115
NCML-1082	2.889	-9.985	-5.919	-6.679	-0.130	0.008	0.581	0.813	0.591	-1.183	-0.153
NCML-1083	4.707	3.606	-2.101	-4.335	-0.092	0.008	3.083	0.268	-2.727	-0.765	-0.176
NCML-1084	0.116	3.333	1.308	-20.270	-0.028	-0.007	0.579	-0.551	0.455	0.258	-0.192

the differences were non-significant (Table I).

For days to pollen shedding, the highest GCA values was observed for line NCML-1083 (4.70), followed by NCML-1082 (2.88) (Table II). The best specific combinations were NCML-1061 × NCML-1082 (7.18) followed by NCML-1061 × NCML-1083 (6.30) (data not shown). When breeding for early maturity, negative values for GCA and SCA effects would be desirable, which were estimated for QPM-1 and all the inbreds from subtropical material (NCML-1061, NCML-1071 and NCML-1078) (Table II), for GCA in particular and for SCA in general. Such findings have also been reported for other inbreds by Mungoma and Pollak (1988), and Revilla *et al*. (1999).

The highest GCA effects for plant height were observed for QPM-1 (7.01) followed by QPM-5 (3.92) and NCML-1083 (3.60) (Table II). Good specific combinations were the hybrids NCML-1078 × NCML-1083 (28.69) followed by QPM-1 × NCML-1084 (16.64) (data not shown). Significant GCA and SCA effects are also reported by Revilla *et al*. (1999) for plant height in certain maize lines. For ear height, GCA effects were more significant than SCA effects (Table I). The predominance of GCA effects suggested that variation among crosses was due mainly to additive rather than nonadditive effects of genes and selection would be effective in improving ear height. Inbreds QPM-1 and QPM-5 came up as the best general combiners with GCA values of 4.99 and 4.03, respectively, followed by QPM-3 (3.26). Hence, material from temperate ecology had good GCA for plant and ear heights (Table II). SCA was the highest for cross QPM-5 × NCML-1082 (12.77), followed by 12.22 and 11.0 for NCML-1078 × NCML-1083 and QPM-1 × NCML-1083, respectively (data not shown).

Temperate lines (QPM-1, QPM-3 and QPM-5) were the best general combiners for leaf area while all other lines showed negative GCAs (Table II). The best specific combination was QPM-5 × NCML-1082 (77.34) followed by NCML-1078 × NCML-1084 (66.88) (data not shown). Almost similar pattern for GCA was displayed by grain yield indicating a direct relationship between leaf area and grain yield. For ears plant^{-1} GCA effects were more significant than SCA effects (Table II), suggesting additive genes predominant. Lines from temperate material (QPM-1 and QPM-3) gave the highest values of GCA followed by NCML-1078 (0.31) and NCML-1071 (0.26) from subtropical material (Table II). SCA effects were eminent in hybrids NCML-1083 × NCML-1084 (0.23) followed by NCML-1061 × NCML-1071 (0.19) (data not shown). Good general combiners for ear weight were NCML-1082 and NCML-1083 (Table II). The highest SCA effects (0.05) were noticed in the hybrid NCML-1071 × NCML-1084 (data not shown).

The best general combiner for high grain moisture at harvest was NCML-1083 (3.08), followed by QPM-3 (1.48) (Table II). The best specific combinations were observed for hybrids NCML-1061 × NCML-1083 (6.00), followed by NCML-1071 × NCML-1078 (2.85) (data not shown). Lines from tropical ecologies were prominent with regard to their GCA effects. Similarly, for kernel rows ear^{-1}, subtropical and tropical materials were distinct for GCA effects (Table II). The best specific combinations were NCML-1071 × NCML-1083 (2.21), followed by NCML-1078 × NCML-1082 (2.12) (data not shown).

Number of kernels row^{-1} followed similar behavior for combining ability as plant and ear heights, and leaf area with temperate lines appeared more distinct for GCA effects (Table II). SCA effects were the highest among hybrids NCML-1082 × NCML-1083 (5.64), followed by QPM-5 × NCML-1082 and QPM-1 × NCML-1083 with SCA value of 4.86 each (data not shown).

For grain yield high estimates of GCA effects were observed in the lines from temperate ecology i.e. QPM-1 (0.168), QPM-3 (0.169) and QPM-5 (0.485) (Table II). The highest SCA effects were observed for hybrids QPM-3 × NCML-1078 (0.890), NCML-1071 × NCML-1084 (0.878) and NCML-1082 × NCML-1083 (0.831) (Table III).

Table III. Specific combining ability (SCA) effects for grain yield for the hybrids in their respective combinations.

Parents	QPM-1	QPM-3	QPM-5	NCML-1061	NCML-1071	NCML-1078	NCML-1082	NCML-1083	NCML-1084
QPM-1	-	-0.524	.0.218	-0.204	0.452	0.572	-0.097	0.472	0.042
QPM-3		-	-0.334	0.103	-0.158	0.890	0.420	-0.015	0.209
QPM-5			-	-0.113	-0.419	0.317	0.629	0.582	0.045
NCML-1061				-	-0.545	-0.392	-0.693	-0.608	-0.121
NCML-1071					-	-0.244	0.348	-0.035	0.878
NCML-1078						-	0.032	0.319	0.277
NCML-1082							-	0.831	-0.109
NCML-1083								-	0.080
NCML-1084									-

Mungoma and Pollak (1988) also reported high GCA and SCA effects for grain yield in their study.

DISCUSSION

Two factors are considered important for the evaluation of an inbred line in the production of hybrid maize; characteristics of the line itself and behavior of the line in a particular hybrid combination. As revealed from the present results, temperate material (QPM-1, QPM-3 and QPM-5) was found superior in terms of GCA effects especially for prominent characters contributing towards high grain yield i.e. plant and ear heights, leaf area, ears plant^{-1}, ear weight and kernels row^{-1}. Tropical material gave eminent GCA effects for days to pollen shedding, ear weight and grain moisture at harvest. Hence, it was concluded that tropical material contributed lateness in flowering which, ultimately, resulted in higher moisture at harvest, more ear weight and greater kernel rows ear^{-1}.

On average, crosses produced by crossing inter-population lines had more positive SCA effects than those produced by crossing intra-population lines. These findings are supported by those by Vasal *et al*. (1992) and Gama *et al*. (1995). As performance of hybrids can be sub-divided into two categories i.e. general and specific combining ability (Rojas & Sprague, 1952), superiority of a line on the basis of combining ability estimates can only be decided precisely after knowing the purpose of a certain breeding programme. Whether, it is to develop high yielding OPVs (open pollinated varieties) or the superior combination of hybrids. Lines which had higher GCA effects can be used in synthetic variety development more effectively. However, when high yielding specific combinations are desired, especially in hybrid maize development, SCA effects could help in the selection parental material for hybridization.

REFERENCES

Beck, D.L., S.K. Vassal and J. Crossa, 1990. Heterosis and combining ability of CIMMYT's tropical early and intermediate maturity maize germplasm. *Maydica*, 35: 279–85

Beck, D.L., S.K. Vassal and J. Crossa, 1991. Heterosis and combining ability among subtropical and temperate intermediate–maturity maize germplasm. *Crop Sci*., 31: 68–73

Crossa, J., S.K. Vasil and D.L. Beck, 1990. Combining ability study in diallel crosses of CIMMYT's tropical late yellow maize germplasm. *Maydica*, 35: 273–8

Gama, E.E.G., A.R. Hallauer, R.G. Ferrao and D.M. Barbosa, 1995. Heterosis in maize single crosses derived from a yellow Tuxpeno variety in Brazil. *Brazilian J. Genet*., 18: 81–5

Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Australian J. Biol. Sci*., 9: 463–93

Morris, M.L., J. Risopoulos and D. Beck, 1999. Genetic changes in farmer–recycled maize seed: A review of the evidence. CIMMYT Econ. Working Paper No. 99–07. Mexico, D.F., CIMMYT. 1 pp.

Mungoma, C. and L.M. Pollak, 1988. Heterotic patterns among ten corn belt and exotic maize populations. *Crop Sci*., 28: 500–4

Paterniani, E., 1990. Maize breeding in the tropics. *CRC Critical Rev. Plant Sci*., 9: 125–54

Payne, W.A., C.W. Wendt, L.R. Hossner and C.E. Gates, 1991. Estimating pearl millet leaf area and specific leaf area. *Agron. J*., 83: 937–41

Revilla, P., A. Butron, R.A. Malvar and A. Ordas, 1999. Relationship among kernel weight, early vigor and growth in maize. *Crop Sci*., 39: 654–8

Rojas, B.A. and G.F. Sprague, 1952. A comparison of variance components in corn yield trials: III. General and specific combining ability and their interaction with locations and years. *Agron. J*., 44: 462–6

Sprague, G.F. and L.A. Tatum, 1942. General vs. specific combining ability in single crosses of corn. *J. Amer. Soc. Agron*., 34: 923–32

Vacaro, E., J. Fernandes, B. Neto, D.G. Pegoraro, C.N. Nuss and L.H. Conceicao, 2002. Combining ability of twelve maize populations. *Pesq. Agropec. Bras., Brasilia*, 37: 67–72

Vasal, S.K., G. Srinivasan, G.C. Han and C.F. Gonzales, 1992. Heterotic patterns of eighty–eight white subtropical CIMMYT maize lines. *Maydica*, 37: 319–27

Vasal, S.K., B.S. Dhillon, G. Srinivasan, S.D. McLean, S.H. Zhang and C.F. Gonzalez, 1994. Breeding intersynthetic hybrids to exploit heterosis in maize. *Maydica*, 39: 183–6

Yan, W. and L.A. Hunt, 2002. Biplot analysis of diallel data. *Crop Sci*., 42: 21–30

(Received 11 April 2004; Accepted 18 July 2004)