COMBINING ABILITY ANALYSIS OF YIELD AND RELATED CHARACTERS IN SINGLE CROSS HYBRIDS OF TROPICAL MAIZE (ZEA MAYS L.)

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S. S. SUJIPRIHATI[1], G. B. SALEH[2*] and E. S. ALI[2]

SUMMARY

Twelve maize (*Zea mays* L.) inbred parents previously selected for their performance were crossed in a diallel scheme. These were evaluated for general combining ability (GCA) and specific combining ability (SCA), at two locations in the Universiti Putra Malaysia. The significant GCA and SCA effects observed reflected the importance of both additive and non-additive gene actions for yield and related characters in the hybrids. However, the SCA variances for all the characters studied were much higher than their respective GCA variances. Results of GCA showed that UPM-SM7-6, UPM-SW-9, and UPM-MT-13 were the best general combiners (giving high positive effects) for grain yield and ear weight at both locations. For days to tasseling, UPM-TW-5 and UPM-TW-12 were the best general combiners for earliness (giving high negative GCA effects), at Field 2 and Share Farm, respectively. For SCA effects, at Field 2, the highest significant positive effect for grain yield was shown by the cross UPM-SW-9 X UPM-SM5-5 which also gave the highest yield (4763 kg/ha). The highest SCA effect for ear weight was given by the cross UPM-SW-9 X UPM-SM5-9, while for plant height by the cross UPM-MT-13 X SM5-9. At Share Farm, the cross UPM-MT-5 X UPM-SM5-4 showed the best performance for grain yield (5948 kg/ha). This cross also gave the highest significant positive SCA effects for grain yield and ear weight. For plant height, the cross UPM-MT-5 X UPM-SM5-5 gave the highest SCA effect. The crosses UPM-MT-5 X UPM-SM5-5 and UPM-SW-9 X UPM-SM5-4 gave the highest negative SCA effects for days to maturity, at Field 2 and Share Farm, respectively, indicating their expression of genes for earliness in maturity. The hybrids showed a high range of performance for all characters investigated, and could be further exploited for their heterotic capacities.

Key words: combining ability, GCA, SCA, hybrids, performance, maize.

Hybrid varieties in maize (*Zea mays* L.) have greater yield potential than the open-pollinated or synthetic varieties, especially when modern production practices are used (CIMMYT, 1988). The first generation of crosses among inbred lines (single-crosses) are usually planted to obtain uniformity in advanced production system.

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The general combining ability (GCA) and specific combining ability (SCA) effects are important indicators of potential value of inbred lines in hybrid combinations. Differences in GCA effects have been attributed to additive, additive X additive, and higher-order interactions of additive genetic effects in the base population, while differences in SCA effects have been attributed to non-additive genetic variance (Falconer, 1981). Ahloowalia and Dhawan (1963) reported that, with respect to SCA, six of 11 inbred lines studied gave significantly higher yields when crossed to inbreds of diverse origin than if crossed to those of closer origin. A similar result was found by Pathullaev (1967) who concluded that, in general, the best combining ability was found in crosses between inbred lines of different geographical origin.

Evaluation of crosses among inbred lines is an important step towards the development of hybrid varieties in maize (Hallauer, 1990). Ideally, this process should be through the evaluation of all possible crosses (diallel crosses), where the merits of each inbred line can be determined. The diallel analysis provides good information on the genetic identity of genotypes especially on dominance-recessive relations and some other genetic interactions.

The present study was carried out as part of the on-going hybrid maize variety development program conducted in Universiti Putra Malaysia (UPM), as reported by Saleh and Yap (1988). In this program, a series of selected maize inbred lines previously developed following six generations of selfing were entered into a diallel crossing scheme, and the crosses were evaluated for combining abilities. The populations from which these inbred lines were extracted had previously been selected based on their performance and general combining ability (GCA) in the early generations. This study was conducted to estimate general combining ability (GCA) and specific combining ability (SCA) among these inbred lines and, consequently, to identify superior single-cross hybrids developed from them.

MATERIALS AND METHODS

Plant materials used as parents for crosses in this study were 12 selected superior maize inbred lines (Table 1). These lines were selected for their performance in previous evaluation trials (Sujiprihati, 1996). All possible crosses among these inbred lines were made in a diallel crossing block. Sowing dates were adjusted to facilitate coincidence in flowering to ensure that reciprocal parental lines were tasselled and silked at the same time for crossing. In the crossing block, ten hybridizations were made for each cross combination, to obtain ample F_1 seeds. The inbred lines were also concurrently selfed to obtain seeds for inbred maintenance purposes. The hand pollination procedure for the crosses and selfing followed that of Russell and Hallauer (1980). A total of 66 cross combinations were obtained through hand pollinations of the inbred lines.

In the evaluation trials, all hybrids were grown at each of the two locations, Field 2 and Share Farm, in UPM. They were located at $3^{\circ} 40'$ North; $101^{\circ} 42'$ East, and 31 meters above sea level. Soil at Field 2 was a sandy loam (56% sand, 23% silt and 21% clay), whereas at the Share Farm was a sandy clay loam (49% sand, 41% clay, and 10% silt). Monthly rainfall ranged from 100 to 500 mm, with an average of 200 mm, and temperatures ranged from 27.5 °C to 29.0 °C. A randomized complete block design was used, with three replications, and planting density of 0.75 m X 0.25 m under normal cultural practices (Sujiprihati, 1996). Equal amounts of seeds of a cross and its reciprocal were combined, to avoid effects of reciprocal differences. Each plot consisted of five 6-m long rows, where only the three middle rows measuring 5-m were used as the harvest area. Data were taken for grain yield (kg/ha), ear weight (g), plant height (cm), days to tasseling (days), and days to maturity (days). Grain yield and ear weight were taken at 15% grain moisture content. Grain yield was represented by the harvest area of each plot (11.25 m^2), while ear weight and plant height were determined from average of 10 ears or plants sampled randomly from each plot. Ear weight was determined as dehusked ear weight per plant. Days to tasseling were taken as the number of days from planting until 50% of plants in the harvest area had their pollen shed, while days to maturity were taken when 95% of the plants in the harvest area had their ear husks dry (turned brown).

Table 1. The 12 selected maize inbred lines used in the diallel cross, their source populations and mean performances for grain weight per plant, days to tasselling and days to silking (Sujiprihati, 1996).

Inbred line	Country of source population	Grain weight per plant (g)	Days to tasseling	Days to silking
UPM-TW-12	Philippines	36.8	52.3	57.9
UPM-TW-5	Philippines	43.5	56.8	61.0
UPM-SM5-9	Philippines	34.7	57.2	57.9
UPM-SM5-5	Philippines	43.9	56.3	61.3
UPM-SM5-4	Philippines	44.9	57.9	63.6
UPM-SM7-6	Philippines	82.6	58.1	60.1
UPM-SM7-10	Philippines	33.1	57.8	62.5
UPM-SM7-11	Philippines	45.3	56.1	60.1
UPM-SW-2	Thailand	35.8	58.9	59.6
UPM-SW-9	Thailand	29.4	60.1	63.0
UPM-MT-13	Indonesia	39.7	56.2	59.4
UPM-MT-5	Indonesia	54.8	55.8	59.9
S.E.		5.73	0.15	0.60

Diallel analysis of combining ability on data obtained from evaluations at both locations was done, using Griffing's (1956) Method 2, Model 1, with parents included. A model with fixed effects was assumed. The diallel analysis was conducted on the F_1 data, separately for each location. Mean values over replications were used in individual location analysis. GCA and SCA mean squares were calculated using the method of Singh and Chaudhary (1977), as follows:

$$g_i = \frac{1}{(p+2)} \left[\Sigma (Y_{i.} + Y_{ii}) - \frac{r}{p} Y.. \right]$$

$$s_{ij} = Y_{ij} - \frac{1}{(p+2)} \left[Y_{i.} + Yii + Y_{.j} + Y_{jj} + \frac{2}{(p+1)(p+2)} Y.. \right]$$

where,

g_i = GCA effect of the i^{th} parent,
g_j = GCA effect of the j^{th} parent,
s_{ij} = SCA effect of the cross between the i^{th} and j^{th} parents, and
p = number of parents involved.

The interactions of GCA and SCA with locations could have been evaluated by combined analysis of the data on the cross combinations and their respective parents from both locations. However, due to the significant interaction of GCA and SCA with locations, a separate analysis was conducted for each location.

RESULTS

At both locations, the GCA and SCA effects were highly significant for grain yield and all other characters studied (Table 2). Three inbred lines, UPM-SM7-6, UPM-SW-9 and UPM-MT-13 consistently showed high positive GCA effects for grain yield at both locations, indicating that they were good general combiners for grain yield (Tables 3 and 4).

Table 2. Mean squares for combining ability for characters measured from a 12-line maize diallel cross evaluated at two locations.

Source of variation	Degrees of Freedom	Mean squares				
		Grain yield	Ear weight	Plant height	Days to tasseling	Days to maturity
At Field 2:						
Block	2	11118850**	6957**	1138**	7.38**	29.20**
Genotype	77	2500448**	1709**	1485**	14.43**	12.07**
GCA	11	849346**	569**	1368**	2.74**	3.64**
SCA	66	830839**	570**	349**	5.15**	4.09**
Error	154	197987	170	63	0.27	0.93
At Share Farm:						
Block	2	439738	5682**	8723**	0.40	54.22**
Genotype	77	4564431**	2876**	1061**	16.37**	11.67**
GCA	11	338640**	277**	478**	3.80**	5.51**
SCA	66	1718617**	1072**	333**	5.73**	3.62**
Error	154	56578	78	58	0.19	0.39

** Significant at $p \leq 0.01$.

UPM-SM7-6 and UPM-MT-13 also had the highest positive GCA effects for ear weight at both locations, measuring 10.2 and 8.3, respectively, at Field 2; 9.2 and 6.0, respectively, at Share Farm.

Three inbred lines, UPM-SM7-6, UPM-SM7-11 and UPM-MT-13 consistently had high positive GCA effects for plant height, at both locations, measuring 5.1, 10.2 and 15.4, respectively, at Field 2; 5.5, 6.9 and 10.6, respectively, at Share Farm.

Table 3. Estimates of GCA effects measured on 12 maize inbred lines, in a diallel cross evaluated at Field 2.

Inbred line	GCA effects				
	Grain yield (kg/ha)	Ear weight (g)	Plant height (cm)	Days to tasseling	Days to maturity
UPM-TW-12	-166.6	-6.88*	-3.63	-0.17	0.44
UPM-TW-5	-402.0**	-8.46*	-6.56**	-0.79**	0.58*
UPM-SM5-9	-397.3**	-9.30**	-19.12**	-0.36**	-0.30
UPM-SM5-5	-40.1	-0.87	-10.76**	-0.40**	-0.11
UPM-SM5-4	-71.0	-0.49	-7.65**	-0.48**	-0.04
UPM-SM7-6	339.8**	10.16**	5.12*	0.69**	0.20
UPM-SM7-10	143.5	5.54	1.00	0.12	0.77**
UPM-SM7-11	-5.7	1.28	10.20**	0.38**	-0.04
UPM-SW-2	8.0	1.38	6.01**	0.21	-1.04**
UPM-SW-9	304.9**	3.84	8.47**	0.48**	-0.20
UPM-MT-13	264.6*	8.28*	15.42**	0.02	-0.61*
UPM-MT-5	-120.0	4.48	1.52	0.29*	0.32
SE (G_i)	113.9	3.33	2.04	0.13	0.25
SE ($G_i - G_j$)	138.2	4.92	3.01	0.20	0.37

*,** Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Table 4. Estimates of GCA effects measured on 12 maize inbred lines, in a diallel cross evaluated at Share Farm.

Inbred line	GCA effects				
	Grain yield (kg/ha)	Ear weight (g)	Plant height (cm)	Days to tasseling	Days to maturity
UPM-TW-12	-55.0	2.30	-7.77**	-0.54**	0.58**
UPM-TW-5	49.2	1.88	-2.03	-0.59**	0.22
UPM-SM5-9	45.0	-1.04	-9.00**	-0.37**	-0.06
UPM-SM5-5	-132.8*	-2.74	-2.17	-0.68**	-0.09
UPM-SM5-4	130.2*	-0.24	1.53	-0.40**	-0.28
UPM-SM7-6	200.0**	9.17**	5.53**	0.65**	0.96**
UPM-SM7-10	-212.7**	-5.64*	-0.07	-0.04	1.03**
UPM-SM7-11	-161.9**	-4.42	6.85**	-0.53**	-0.06
UPM-SW-2	-108.5	-1.49	-5.58**	0.15	-1.13**
UPM-SW-9	131.8*	1.30	1.07	0.82**	-0.66**
UPM-MT-13	253.4**	5.95**	10.60**	-0.02	-0.33*
UPM-MT-5	-138.6*	-5.02*	1.03	0.46**	-0.18
SE (G_i)	60.9	2.26	1.95	0.11	0.16
SE ($G_i - G_j$)	89.9	3.34	2.88	0.17	0.24

*,** Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

With regard to days to tasseling, UPM-TW-5 gave the highest negative GCA effects at Field 2 (estimated as -0.79), while at Share Farm, the highest negative value was given by UPM-SM5-5 (estimated as -0.68). For days to maturity, UPM-SW-2 was the best early general combiner at both locations (estimated as -1.04 and -1.13, respectively at Field 2 and Share Farm).

The SCA effects shown by the crosses on the characters studied at Field 2 and Share Farm, are presented in Tables 5 and 6, respectively. The crosses listed are the ten best cross combinations based on their positive SCA effects for grain yield, supported by general performance for the other characters at each location. At Field 2, high positive SCA effects for grain yield were shown by the crosses UPM-SW-9 X UPM-SM5-5 (1855.6), UPM-MT-13 X UPM-SM5-9 (1223.3), and UPM-SW-9 X UPM-SM5-9 (1168.3) (Table 5). At Share Farm, the crosses UPM-MT-5 X UPM-SM5-4, UPM-MT-5 X UPM-SM5-9 and UPM-MT-5 X UPM-SM5-5 gave high positive SCA effects, with estimates of 1934.0, 1582.1 and 1503.3, respectively (Table 6). The best specific combiners at each location mentioned (UPM-SW-9 X UPM-SM5-5 at Field 2, and UPM-MT-5 X UPM-SM5-4 at Share Farm) also revealed the best performance for grain yield at the specific location (4763 kg/ha and 5948 kg/ha, respectively, for the two crosses), as presented in Tables 7 and 8.

Table 5. Estimates of SCA effects for the top 10 specific combiners from a diallel cross among 12 maize inbred lines, evaluated at Field 2.

Cross combination	SCA effects				
	Grain yield (kg/ha)	Ear weight (g)	Plant height (cm)	Days to tasseling	Days to maturity
UPM-SM7-6 X UPM-TW-12	1050.8**	34.3**	13.31*	-2.40**	-0.37
UPM-SM7-11 X UPM-TW-12	929.7**	31.0**	11.8	-0.75	-1.47
UPM-MT-5 X UPM-TW-12	584.7**	28.4*	21.0**	-1.99**	-1.16
UPM-MT-5 X UPM-TW-5	1005.3**	38.5**	12.1	-0.04	-0.64
UPM-SW-9 X UPM-SM5-9	1168.3**	39.8**	36.4**	-1.66**	1.44
UPM-MT-13 X UPM-SM5-9	1223.3**	33.4**	38.1**	-1.21**	-0.16
UPM-MT-5 X UPM-SM5-5	1008.0**	21.3	20.1**	-1.47**	-3.42**
UPM-SW-9 X UPM-SM5-5	1855.6**	38.7**	17.0*	-1.61**	0.25
UPM-SW-2 X UPM-SM5-4	1019.1**	28.7**	17.5**	-2.28**	1.66*
UPM-MT-13 X UPM-SM5-4	962.5*	25.9*	10.8	-0.75	-2.75**
SE (S_{ij})	378.9	11.1	6.8	0.44	0.82
SE ($S_{ij} . S_{ik}$)	606.4	17.7	10.9	0.71	1.32
SE ($S_{ij} . S_{kl}$)	582.6	17.0	10.4	0.68	1.27

For ear weight, the highest positive SCA effect was given by UPM-SW-9X UPM-SM5-9 (39.8) at Field 2, while it was UPM-MT-5 X UPM-SM5-4 at Share Farm (43.9). For plant height, the highest SCA effects were shown by the cross UPM-MT-13 X UPM-SM5-9 (38.1) at Field 2, and by UPM-MT-5 X UPM-SM5-5 (30.1) at Share Farm.

For days to tasseling, UPM-SM7-6 X UPM-TW-12 were the best specific combiners at Field 2 (SCA effects of -2.40), while UPM-SW-9 X UPM-SM5-4 was the best at Share Farm (SCA effects of -4.31). For days to maturity, the cross combination of UPM-MT-5 X UPM-SM5-5 gave the best negative SCA estimates of -3.42, indicating earliness at Field 2; while the best negative value was given by UPM-SW-9 X UPM-SM5-4 at Share Farm (SCA estimates of -3.39).

Table 6. Estimates of SCA effects for the top 10 specific combiners from a diallel cross among 12 maize inbred lines at Share Farm.

	SCA effects				
	Grain yield (kg/ha)	Ear weight (g)	Plant height (cm)	Days to tasseling	Days to maturity
UPM-SM5-9 X UPM-TW-5	1002.2**	36.4**	20.7**	-2.00**	0.16
UPM-SM5-5 X UPM-TW-12	1345.6**	37.2**	15.6*	-0.03	1.18*
UPM-SW5-4 X UPM-TW-12	998.4**	34.5**	19.4**	-0.31	0.37
UPM-SW-2 X UPM-TW-5	999.6**	30.3**	26.1**	-3.45**	0.59
UPM-SW-9 X UPM-SM5-9	1099.9**	33.4**	27.7**	-1.33**	0.73
UPM-MT-5 X UPM-SM5-9	1582.1**	27.3**	16.5**	-1.98**	-2.41**
UPM-MT-5 X UPM-SM5-5	1503.3**	36.7**	30.1**	0.33	-0.72
UPM-SW-9 X UPM-SM5-4	1374.7**	37.6**	-3.2	-4.31**	-3.39**
UPM-MT-13 X UPM-SM5-4	1319.7**	30.2**	5.1	-0.48	-1.72**
UPM-MT-5 X UPM-SM5-4	1934.0**	43.9**	16.2*	-0.62	-1.53**
SE (S_{ij})	202.6	7.5	6.5	0.37	0.53
SE ($S_{ij} - S_{ik}$)	324.2	12.0	10.4	0.60	0.85
SE ($S_{ij} - S_{kl}$)	311.4	11.6	10.0	0.58	0.82

Table 7. Performance of the top 10 yielding maize hybrids from the diallel crosses at Field 2.

Hybrid/ check variety	Grain Yield (kg/ha)	Ear weight (g)	Plant height (cm)	Days to tasseling	Days to maturity
Hybrid:					
UPM-SM7-6 X UPM-TW-12	3867	119.3	157.9	50.3	92.0
UPM-SM7-11 X UPM-TW-12	3400	107.2	161.5	51.7	90.7
UPM-MT-5 X UPM-TW-12	2941	98.8	162.0	50.3	91.3
UPM-MT-5 X UPM-TW-5	3126	107.3	150.1	51.7	92.0
UPM-SW-9 X UPM-SM5-9	3719	116.1	168.9	50.7	92.7
UPM-MT-13 X UPM-SM5-9	3733	114.1	177.4	50.7	90.7
UPM-MT-5 X UPM-SM5-9	3133	89.3	145.6	50.7	88.3
UPM-SW-9 X UPM-SM5-5	4763	123.4	157.8	50.7	91.7
UPM-SW-2 X UPM-SM5-4	3741	111.4	158.6	49.7	89.0
UPM-MT-13 X UPM-SM5-4	3941	115.5	161.7	51.0	88.3
Check variety:					
Suwan 1	3156	114.0	168.9	52.3	95.0
Suwan 3	1896	55.4	139.1	52.3	94.0
Metro	3400	108.7	223.0	54.0	92.7
S.E.	261.8	6.92	7.99	0.45	0.80

Table 8. Performance of the top 10 yielding maize hybrids from the diallel crosses at Share Farm.

Hybrid/ check variety	Grain yield (kg/ha)	Ear weight (g)	Plant height (cm)	Days to tasseling	Days to maturity
Hybrid:					
UPM-SM5-9 X UPM-TW-5	5015	149.2	169.0	49.0	91.7
UPM-SM5-5 X UPM-TW-12	5185	148.4	170.6	50.7	92.7
UPM-SW5-4 X UPM-TW-12	5096	150.1	178.2	50.7	91.7
UPM-SW-2 X UPM-TW-5	4963	142.3	183.5	48.0	90.7
UPM-SW-9 X UPM-SM5-9	5296	145.3	184.8	51.0	91.0
UPM-MT-5 X UPM-SM5-9	5511	132.8	173.2	50.0	88.3
UPM-MT-5 X UPM-SM5-5	5259	140.6	194.0	52.0	90.0
UPM-SW-9 X UPM-SM5-4	5659	150.3	164.4	48.0	86.7
UPM-MT-13 X UPM-SM5-4	5726	147.5	182.4	51.0	88.7
UPM-MT-5 X UPM-SM5-4	5948	150.3	183.7	51.0	89.0
Check variety:					
Suwan 1	5430	139.1	206.6	52.0	89.7
Suwan 3	4474	144.2	172.6	52.3	91.3
Metro	5104	121.7	227.0	54.0	93.0
S.E.	150.2	3.26	6.73	0.67	0.72

DISCUSSION

The results showed that both GCA and SCA effects were significant for grain yield and other related characters studied, indicating that both additive and non-additive gene actions were important for grain yield and other characters studied in the hybrids generated from the diallel crosses. Negative effects for the flowering character and maturity were indications of the presence of genes for earliness, which is a desirable trait possessed by the inbred lines concerned.

From the results on GCA, the inbreds UPM-SM7-6, UPM-SW-9 and UPM-MT-13 were the best general combiners for grain yield, at both locations. For ear weight, UPM-SM7-6 and UPM-MT-13 were the best general combiners at both locations. It was noted that inbred lines showing high GCA for the grain yield also had average to high GCA for ear weight. In contrast, inbred lines showing high GCA for ear weight did not necessarily have high GCA for grain yield. For SCA effects, at Field 2, the highest significant positive effect for grain yield was given by the cross UPM-SW-9 X UPM-SM5-5 which also showed the best yield performance. At Share Farm, the cross UPM-MT-5 X UPM-SM5-4 showed the best performance for grain yield, and gave the highest significant positive SCA effects for grain yield, ear weight, and grain weight per ear.

As a basic principle, Sprague and Tatum (1942) emphasized that SCA is more important than GCA among selected inbred lines. However, GCA is relatively more important than SCA among unselected inbred lines, for yield characters. They interpreted SCA as an indicator for the predominance of genes having dominance and epistatic effects, while GCA as indicative for predominance of genes having largely additive effects. These conclusions were in agreement with the results of this study involving selected inbred lines.

This was due to the non-additive gene effects, which comprised a major part of the genetic variation for most characters among the selected maize inbred lines which were used in the production of single cross hybrids. In addition, for all characters studied, the SCA variances were higher than those for GCA, indicating that non-additive gene effects were greater than the additive ones. The importance of non-additive gene action was also reported by Hansen et al. (1977), Beck et al. (1991), and Alika (1994). They also found similar results for ear length, ear height, and ear diameter. However, some other researchers found that the additive gene effect was relatively more important especially in maize (Qadri et al., 1983; Lin and Chen, 1986). These contrasting reports could be attributed to differences in size, nature, and diversity of the materials studied, the environments in which the experiments were conducted, and the methods of analysis employed.

CONCLUSION

The single cross hybrids tested in this study showed a high range of performance for all characters investigated. As such, they could be exploited further for their heterotic capacities. Both additive and non-additive gene effects were significant for grain yield and the yield components studied. The inbred lines that revealed strong GCA effects could be further utilized as sources for population improvement towards the accumulation of favourable additive genes in populations. Those with strong SCA effects could be advanced for hybrid variety release after other yield stability factors have been considered.

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