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Heterosis and combining abilities in a diallel cross of seven CIMMYT corn inbred lines in Malaysian conditions

(Heterosis dan keupayaan bergabung pada kacukan dialel tujuh titisan baka seturunan jagung dari CIMMYT dalam keadaan Malaysia)

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Key words: heterosis, diallel cross, specific combining ability, general combining ability

Abstrak

Heterosis bagi 21 hibrid dan tujuh titisan induk telah dinilai untuk hasil. Prestasi purata hibrid ini lebih baik daripada induk baka seturunan bagi semua kacukan. Kesemua kacukan memberi hasil melebihi induk yang berhasil tinggi, dan juga bagi nilai hasil pertengahan induk. Walau bagaimanapun, apabila dibandingkan dengan Suwan 3 varieti komersil yang terbaik, hanya lima gabungan F_1 yang menunjukkan heterosis yang positif dengan nilainya berjulat dari 0.1% hingga 8%.

Analisis dialel untuk keupayaan bergabung menunjukkan bahawa sebahagian besar varian genetik untuk tempoh 50% berbunga, ketinggian pokok dan tongkol berkait secara ketara dengan keupayaan bergabung am. Keadaan ini menunjukkan pentingnya gen tambah dalam penentuan genetik ciri tersebut. Hasil dan aspek tongkol, sebaliknya lebih dipengaruhi oleh gen tak tambah seperti yang ditunjukkan oleh kesan keupayaan bergabung khusus yang ketara.

Abstract

Twenty-one hybrids and seven parental lines were evaluated for heterosis in yield. Mean performance of hybrids was superior to that of the parental inbreds in all the crosses. All the hybrids outyielded their better parents and their mid-parent values. However, compared against Suwan 3, the best commercial variety, only five F_1 combinations showed positive heterosis, the values of which ranged from 0.1% to 8%.

The diallel analysis for combining ability indicated that a large part of the total genetic variance observed for 50% tasseling, plant and ear heights was associated with significant general combining ability effects, indicating the importance of additive genes in the genetic determination of these characters. Yield and ear aspect, however, were largely controlled by non-additive genes as reflected by the significant specific combining ability effects.

Introduction

In recent years, MARDI has shown an increased interest in hybrid oriented products which led to an increased importance of the maize hybrid breeding programme. The immediate task that faced the hybrid breeding programme was to develop inbreds from suitable germplasm pools and to test these materials for their combining abilities in hybrid combinations.

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Inbreds for the hybrid maize breeding programme are being developed locally from the limited gene pools available. In addition, inbred lines with tropical adaptation are available from CIMMYT on request. The utility of CIMMYT germplasm for hybrid development was demonstrated by Han et al. (1991) who identified several high-yielding hybrids from crosses involving S_3 lines derived from CIMMYT pools and populations. Many superior interpopulation hybrids were identified in their study, in addition to a significant number of intrapopulation hybrids. The possibility of obtaining high-yielding intrapopulation hybrids was further demonstrated by Chutkaew et al. (1985). MARDI's hybrid maize breeding programme is developing both inter and intrapopulation hybrids. CIMMYT inbred lines were used, especially to exploit the broad genetic variability in its maize germplasm. This paper reports on the performance of seven CIMMYT downy mildew-resistant inbred lines, especially with regard to their performance in hybrid combinations.

Materials and methods

The seven inbred parents and 21 F_1s from a diallel crossing of these parents were obtained from CIMMYT Thailand. The parents were from LY-DMR pool C_3-S_2 (0%) -1 (P_1) to C_3-S_2 (0%) -7 (P_7). Though these are downy mildew-resistant lines, the disease was not evaluated because its occurrence in Malaysia is very rare, and the method of screening against this disease locally has not yet been developed.

The parental lines and their crosses (excluding reciprocals) together with three check varieties were evaluated in 1992 in Bertam following a group balanced block design (two replications of 32 treatments each and grouped into four blocks). Each plot consisted of two rows of 5 m long and spaced 75 cm between rows. The plant spacing within a row was 50 cm with 2 plants/point. Data were recorded from all the plants within each plot. Traits measured were 50% tasseling, plant and ear heights, number of lodged plants per plot, field weight, cob moisture content, husk cover and ear aspect. Except for 50% tasseling, these characteristics were measured just before harvest or during harvesting. Field weight per plot and cob moisture content were used to compute dry grain yield per hectare. For husk cover, husks tightly covering the tip of ears were given a value of 1, and a badly exposed ear tip a value of 5. Similarly for ear aspect, a well-formed and fully filled ear was given a value of 1 while badly filled and deformed ear a value of 5.

From the data obtained, heterosis, heterobeltiosis (as defined by Fonseca and Patterson 1968) and standard heterosis (as defined by Virmani et al. 1982) were calculated for grain yield, and expressed as the percentage of deviation over mid-parent, better parent and best commercial variety (Suwan 3). The procedure employed for combining ability analysis was based on Griffing's (1956) Method 2 analysis. The procedure was used to analyse the GCA (general combining ability) and SCA (specific combining ability) estimates for all the traits evaluated.

Results and discussion

Heterosis

The yield advantage and means for the seven traits in the seven parents and 21 F_1 hybrids are shown in *Table 1*. On the average, hybrids showed superiority over inbred lines in all the traits. The F_1 hybrids showed a large increase in yield. However, this increase in yield was accompanied by increases in both plant and ear heights. Days to 50% tasseling and number of lodged plants were both reduced while the ear aspect and husk cover were both improved in the hybrids. The taller plants of hybrids had reduced number of lodged plants per plot due most probably to the better development of their root systems, thus reducing root lodging compared with non-hybrids. The enhanced root vigour, depth

Table 1. Heterosis, heterobeltoisis and standard heterosis for yield and mean values for days to 50% tasseling, plant and ear heights, lodging, husk cover and ear aspect for seven CIMMYT inbred lines and their crosses

Pedigree	Grain yield				50% tass. (days)	Plant height (cm)	Ear height (cm)	Lodge. (no./ plot)	Husk cover	Ear aspect
	Heterosis (%)	Hetero-beltoisis (%)	Standard heterosis (%)	Mean (kg/ha)						
P1 x P2	115.9	85.1	–4.0	5 974	52.0	242.2	134.0	0	1.0	2
P1 x P3	87.0	84.4	–7.2	5 867	54.0	210.0	107.1	1	1.0	1
P1 x P4	54.5	43.6	–15.9	4 640	53.0	191.5	101.0	0	2.0	2
P1 x P5	77.9	67.6	–15.7	4 213	53.5	203.0	109.0	0	1.5	2
P1 x P6	88.5	86.0	–6.4	5 174	52.5	222.8	116.0	0	2.0	2
P1 x P7	64.8	57.5	–13.0	4 800	53.5	209.1	111.0	0	2.0	2
P2 x P3	91.9	66.9	–18.8	5 120	53.0	238.0	129.0	0	2.0	2
P2 x P4	86.0	50.1	–12.1	5 547	51.0	214.7	123.0	0	1.5	2
P2 x P5	118.6	97.7	–12.1	4 800	52.0	217.4	124.0	0	1.5	2
P2 x P6	94.2	73.7	–14.9	5 227	51.5	231.8	138.0	0	2.0	2
P2 x P7	85.0	52.7	–15.6	4 214	54.5	247.8	139.0	0	1.5	2
P3 x P4	66.1	52.0	–11.0	4 267	54.5	197.0	108.0	0	2.5	2
P3 x P5	99.6	91.1	–7.1	4 320	53.5	195.4	108.0	0	1.0	1
P3 x P6	69.6	68.9	–17.2	4 000	53.5	211.3	127.0	0	2.5	3
P3 x P7	99.6	87.6	3.7	5 707	54.0	231.9	131.1	1	2.0	2
P4 x P5	60.6	41.5	–17.1	3 840	54.0	186.5	117.0	0	2.0	2
P4 x P6	65.8	52.2	–10.8	4 534	52.0	200.6	122.0	0	2.0	3
P4 x P7	78.0	73.0	1.3	5 174	54.0	207.2	120.0	0	1.0	1
P5 x P6	114.2	104.3	0.1	5 013	52.0	204.2	126.0	0	2.0	2
P5 x P7	114.4	93.4	6.9	5 654	54.0	212.2	129.0	0	1.0	2
P6 x P7	107.6	95.9	8.2	5 920	52.5	232.2	131.0	0	2.0	3
Bertam 8805	–	–	–	5 970	50.0	220.0	104.1	1	3.0	3
Bertam 8601	–	–	–	5 547	52.0	229.3	118.1	1	1.5	1
Suwan 3	–	–	–	5 333	52.0	220.8	112.0	0	2.5	2
P1	–	–	–	2 507	56.0	164.0	68.0	0	1.0	3
P2	–	–	–	1 440	53.5	186.4	103.1	1	2.0	5
P3	–	–	–	2 187	56.0	184.9	92.0	0	2.0	4
P4	–	–	–	3 147	55.5	154.7	90.0	0	1.5	2
P5	–	–	–	2 267	55.0	145.6	94.1	1	1.0	2
P6	–	–	–	1 974	55.0	158.8	90.0	0	1.5	4
P7	–	–	–	2 827	57.0	183.8	104.0	0	1.5	2
P6*	–	–	–	4 000	52.0	191.6	120.2	2	2.0	2
Mean	87.6	72.6	–8.5	4 413	53.41	204.6	113.9	0.25	1.7	2.3
C.V. (%)	22.5	26.7	–97.4	22.0	1.82	5.4	7.7	49.21	37.0	39.1
SE/plot	–	–	–	969.7	0.97	1.1	8.8	0.09	0.6	0.7

*This parental entry is included to fill up the vacant plots in the field experimental design

and volume were also noticed in the hybrids of triticale (Barker and Varugese 1992).

With respect to yield advantage, the mid-parent heterosis for yield ranged from 55% to 119% with a mean of 88%. All the 21 hybrids outyielded the mid-parents significantly. The heterobeltoisis values for yield ranged from 42% to 104% with all the 21 hybrids again significantly outyielding the better parents. The high level of mid-parent and better-parent heterosis obtained contrasted starkly with the low levels of heterosis of 5–10% obtained in heterotic studies of others (Yap and Tan 1973; Hallauer and Miranda 1981; Beck et al. 1990, 1991; Crossa et al. 1990; Vasal et al. 1992). This difference in heterosis levels obtained could be due to the fact that crosses between germplasm pools or between varieties were evaluated, whereas in this study the crosses were between early generation inbred lines. However, when compared with the best commercial variety (Suwan 3) which yielded 3 542 kg/ha, only five F_1 combinations showed positive standard heterosis. The yield advantage obtained (0.1–8%), however, was not significant. All the other combinations showed negative standard heterosis with 13 F_1 combinations producing significantly lower yields than Suwan 3.

Combining ability analysis

The variances due to both GCA and SCA were highly significant *(Table 2)* for the traits 50% tasseling, plant and ear heights, indicating considerable genetic diversity for these characters among the parental lines used in this study. They also indicated the involvement of both additive and non-additive types of gene action in the control of these traits. The higher magnitude of variances due to GCA compared with SCA variances for the above characters suggested a predominant additive type of gene action.

The variance was highly significant for SCA but non-significant for GCA for the traits grain yield and ear aspect, indicating

Table 2. Analysis of variance of diallel crosses of SW-DMR 8935-1 among S_2 lines for grain yield, 50% tasseling, plant and ear heights, husk cover and ear aspect

Source of variation	df	MS	F-value	Probability
Grain yield				
GCA	6	267 951.00	0.60ns	
SCA	21	2 147 451.00	4.57**	0.001–0.01
Error	31	470 160.00		
50% tasseling				
GCA	6	3.19	6.79**	0.001–0.01
SCA	21	1.76	3.74**	0.001–0.01
Error	31	0.74		
Plant height				
GCA	6	1 014.67	16.60**	0.001–0.01
SCA	21	608.19	9.95**	0.001–0.01
Error	31	61.14		
Ear height				
GCA	6	414.11	10.74**	0.001–0.01
SCA	21	257.37	6.67**	0.001–0.01
Error	31	38.56		
Husk cover				
GCA	6	0.32	1.52ns	
SCA	21	0.19	0.90ns	
Error	31	0.21		
Ear aspect				
GCA	6	0.14	0.64ns	
SCA	21	0.96	4.30**	0.001–0.01
Error	31	0.22		

the greater involvement of the dominant type of gene action in the control of these traits. Many previous studies, however, obtained higher magnitudes of variances due to GCA than of SCA for grain yield (Yap and Tan 1973; Beck et al. 1990, 1991; Crossa et al. 1990; Vasal et al. 1992). This difference in the results obtained could be due to the fact that all these workers used hybrids between germplasm pools or of varieties, whereas in this experiment inbred lines developed from a common germplasm pool were used. For husk cover, the variances were both insignificant for GCA and SCA.

General combining ability effects

P7, followed by P1 and P4, was the best general combiner for grain yield *(Table 3)*. For 50% tasseling, P7 was again the best general combiner, followed by P3 and P1. For plant and ear heights, the best general combiner was P2, followed by P7. The best general combiner for husk cover was P6, followed by P3. Lastly, P2 and P3 were the best general combiners for ear aspect.

Overall, the analyses indicated that P7 was by far the best general combiner for yield, 50% tasseling, and plant and ear heights, indicating that it might be a good entry for the formation of a composite variety or as a source germplasm for the maize improvement programme.

Specific combining ability effects

Out of the 21 crosses, 17 showed positive SCA effects for grain yield *(Table 4)*. The three best hybrids were P1 x P2, P1 x P3 and P6x P7. It may be noted that good general combiners may not necessarily produce good F_1 combinations as observed in this study whereby P2 and P3 showed negative GCA effects but the hybrids formed against P1 exhibited highest and positive SCA effects.

When 50% tasseling was considered, only three hybrid combinations showed small positive SCA effects, while the rest of the cross combinations exhibited small negative effects, indicating very small positive or negative heterosis in this trait when crosses were made. It also indicated that generally, when crosses are made, the F_1s are usually slightly earlier flowering and maturing than the parents *(Table 1)*. The three best cross-combinations with respect to the SCA effects for 50% tasseling were P2 x P7, P3 x P4 and P4 x P5.

The three crosses showing high SCA effects for plant height were P1 x P2, P1 x P6 and P6 x P7. Out of the 21 crosses, only one cross, P1 x P7, had negative SCA effects. In hybrid development, crosses with low positive SCA effects for plant height are more desirable than those with high positive SCA effects to avoid plant lodging from increased heights.

Table 3. Estimates of general combining ability effects for yield, 50% tasseling, plant and ear heights, husk cover and ear aspects

Parent	Grain yield	50% tass.	Plant height	Ear height	Husk cover	Ear aspect
P1	143.85	0.12	–1.97	–10.91	–0.20	–0.14
P2	–69.43	–0.94	15.61	9.02	0.02	0.13
P3	–81.37	0.56	3.24	–1.95	0.19	0.13
P4	–10.10	0.01	–13.04	–4.61	0.08	–0.14
P5	–223.48	0.01	–12.73	–1.02	–0.25	–0.09
P6	–63.48	–0.55	–0.41	3.20	0.25	0.08
P7	304.02	0.79	9.29	6.27	–0.09	0.02
SE (gi)*	211.61	0.21	2.41	1.92	0.14	0.15
SE of diff. (gi – gj)	118.70	0.32	3.69	2.93	0.21	0.22

*gi is the estimated average performance of a parent line i crossed with each of the other parent lines, compared with the overall mean performance of the P parents and 1 set of F_1s

Table 4. Estimates of specific combining ability effects in a 7-parent F_1 diallel for different traits, based on Griffing (1956)

Cross	Grain yield	50% tass.	Plant height	Ear height	Husk cover	Ear aspect
P1 x P2	1 600.97	–0.86	25.51	21.90	–0.49	–0.40
P1 x P3	1 505.92	–0.36	5.73	5.53	–0.65	–0.40
P1 x P4	208.14	–0.81	3.51	2.53	0.46	–0.63
P1 x P5	–5.47	–0.31	14.64	7.19	0.29	0.32
P1 x P6	795.03	–0.75	22.12	10.33	0.29	–0.35
P1 x P7	54.03	–1.08	–1.28	1.35	0.63	–0.29
P2 x P3	972.69	–0.31	16.16	8.39	0.13	–0.68
P2 x P4	1 327.92	–1.75	9.08	4.30	–0.26	–0.40
P2 x P5	794.81	–0.75	11.47	1.96	0.07	–0.46
P2 x P6	1 061.31	–0.69	13.60	12.09	0.07	–0.63
P2 x P7	–319.19	0.97	19.90	9.42	–0.10	–0.07
P3 x P4	59.86	0.25	3.75	0.82	0.57	–0.40
P3 x P5	326.75	–0.75	1.89	–2.37	–0.60	–0.46
P3 x P6	–153.25	–0.19	5.42	11.71	0.40	–1.13
P3 x P7	1 185.75	–1.03	16.32	12.39	0.24	–0.57
P4 x P5	–224.53	0.31	9.22	8.54	0.51	–0.68
P4 x P6	308.97	–1.14	11.04	9.17	0.01	–0.35
P4 x P7	581.47	–0.47	7.94	4.30	–0.65	–0.29
P5 x P6	1 001.86	–0.64	14.33	9.83	0.35	–0.90
P5 x P7	1 274.86	–0.47	12.43	9.46	–0.32	–0.35
P6 x P7	1 381.36	–1.42	20.26	7.24	0.18	–0.51
SE of diff. (Sii – Sjj)	722.77	0.73	8.24	6.55	0.48	0.50
SE of diff. (Sij – Sik)	914.24	0.92	10.43	8.28	0.60	0.63

For ear height, the three crosses showing highest SCA effects were P1 x P2, P3 x P7 and P2 x P6. Here again there was one cross, i.e. P3 x P5, that had negative SCA effect. All other crosses had small positive SCA values.

The experimental results indicated that there were only two combinations, i.e. P5 x P7 and P6 x P7 that had high enough yield advantage (7–8%) over Suwan 3 *(Table 1)*. Barker and Varugese (1992) stipulated that crosses with mean high-parent heterosis of over 25% in marginal environments indicate the potential of developing hybrids. The mean and individual high-parent heterosis levels of the above two crosses were above 70%. The components of these combinations could therefore be developed further for making these crosses and could also be tested in hybrid combinations against other unrelated inbreds from which there are possibilities of obtaining crosses with higher heterosis. The results also showed that P7 had high and significant GCA effects. This line could therefore be used to develop a high-yielding germplasm pool.

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