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Performance of grain maize varietal crosses and their uses in varietal improvement

(Prestasi kacukan varieti jagung bijian dan kegunaannya dalam pembaikan varieti)

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Key words: heterosis, grain maize, genetic diversity, varietal crosses

Abstrak

Enam varieti jagung bijian yang paling berpotensi di Malaysia dijadikan induk dalam satu skim kacukan dialel. Induk-induk ini dan kacukan dialel yang dihasilkan (tidak termasuk kacukan salingan) telah dinilai heterosis hasilnya. Pada keseluruhannya, hasil induk melebihi hasil kacukan. Nakhorn Suwan 1 dan Pop. 28 ialah induk yang berhasil paling tinggi. Hanya dua daripada 15 kacukan menunjukkan heterosis positif berbanding dengan induk yang berhasil lebih tinggi. Kacukan Bertam 8805 x Suwan 3 dan Bertam 8701 x Suwan 3 berpotensi sebagai bahan untuk memulakan kerja kacukan.

Analisis keupayaan bergabung menunjukkan bahawa varieti Nakhorn Suwan 1 dan Bertam 8805 penggabung terbaik untuk hasil dan sifat pertumbuhan lain. Dengan itu, varieti-varieti ini pilihan terbaik untuk pembentukan varieti komposit. Untuk keupayaan bergabung khas, kacukan terbaik dari segi hasil ialah Bertam 8701 x Suwan 3, Bertam 8602 x Pop. 28 dan Bertam 8701 x Nakhorn Suwan 1. Dengan itu, seturunan yang berpotensi boleh dimajukan daripada induk kacukan ini untuk memajukan varieti hibrid.

Abstract

Six grain maize varieties with greatest potential in Malaysia were used as the parents in a diallel hybridisation scheme. These parental varieties and the diallel crosses obtained (excluding reciprocal crosses) were analysed for yield heterosis. On the average, the parents were higher yielding than the hybrids. Nakhorn Suwan 1 and Pop. 28 were the highest yielding parental varieties. Only two of the 15 varietal crosses showed positive high-parent heterosis. The combinations Bertam 8805 x Suwan 3 and Bertam 8701 x Suwan 3 are potential materials for initiating hybrid work.

The analyses of combining ability indicate that Nakhorn Suwan 1 and Bertam 8805 were the best general combiners for yield and other growth characters; they could be used to develop composite varieties. For specific combining ability, the best crosses for yield were Bertam 8701 x Suwan 3, Bertam 8602 x Pop. 28 and Bertam 8701 x Nakhorn Suwan 1. Potential inbreds could, therefore, be developed from the parents of these crosses to develop hybrid varieties.

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Introduction

Hybrid maize represents one of the most far-reaching developments in applied biology in the latter half of the 20th century. This assertion may be true in general. However, it carries less weight in many developing countries where the widespread adoption of hybrid maize is frequently aspired to but seldom realised.

Although relatively little research has been done on hybrid maize in many developing countries, hybrids show less yield advantage when grown under lowland tropical conditions. Furthermore, the superiority of hybrid germplasm diminishes when it is grown under low levels of inputs and management. In some marginal environments under subsistence farming conditions, the yield difference between hybrids and open-pollinated varieties becomes narrow or non-existent (Low and Waddington 1989).

Development of highly inbred and rigidly screened lines for conventional hybrid development is expensive and time-consuming. Due to inherent problems, such as marginal and infertile growth areas, drought, weeds, pests, diseases, labour shortages as well as inadequate incentives for producers and marketing problems, the use of hybrid seeds does not guarantee a higher production in maize cultivation. The cost of planting materials can be reduced and heterosis exploited by making and planting so-called non-conventional hybrids, i.e. varietal F_1 hybrids or topcrosses. This paper investigates the heterotic patterns and combining ability among the more popular and higher yielding varieties available at MARDI as knowledge of these factors is important to identify suitable germplasm for hybrid development.

Materials and methods

Six varieties which formed the diallel in the study, were Bertam 8805, Bertam 8602, Bertam 8701, Pop. 28, Suwan 3 and Nakhorn Suwan 1. These varieties represent the highest yielding varieties in various yield trials carried out over the years at Bertam. They also represent a very diverse germplasm *(Table 1)*. The varieties were crossed in all possible combinations, excluding reciprocals. Each cross was made by planting the male and female parents in eight alternate 40 m rows. The plant spacing was 50 cm within row with two plants per point and 75 cm between rows. At tasseling, plants of female parents were completely detasseled to facilitate cross pollination. Crossed seeds from the female parent were bulked for use in subsequent experiment. Crossed seeds of other combinations were produced in a similar manner. However, planting was staggered at 2-week intervals to avoid pollen contamination.

Table 1. Pedigree of six grain maize varieties

Variety	Pedigree
Bertam 8805	CIMMYT Pop. 24, 26, 27, 28(r)-C-FS, 36, Ac 7728, Pool 21, 22, 25, 26, IBP Var. 1 and Bertam 8602.
Bertam 8602	Suwan 1, P 6181, 3H 001, 2H 107, XC F34 and 2H 106.
Bertam 8701	Half-sib population of Suwan 1.
Pop. 28	Tropical late-maturing yellow dent with high yield potential. It is a mixture of Caribbean, Mexican, Central American and Brazilian materials.
Suwan 3	Developed basically from Suwan 1 from 1976 to 1987. In the course of improvement, materials like IPTT 34, H 3369A, SR 52, Florida Sun (Am. Bajiox Varios temp.), U.SA. 342 and Corn Belt Comp., all crossed with Suwan 1 (s) C4, were added.
Nakhorn Suwan 1	Varietal cross random-mated for two generations of Suwan 1 (MMS) C_2F_2 x Pop. 28 DMR (Amarillo Dentado).

The six parents and 15 crosses were evaluated at Bertam, Seberang Perai and at Ladang Lambor, Perak. The experimental plots at Bertam were irrigated as the need arose, but the plots at Ladang Lambor were rainfed.

The experimental design used was a randomised complete block with four replications at each location. The experimental unit was a 5 m four-row plot, each spaced 75 cm apart. Plots were over-planted and thinned to two plants per hill, with 50 cm distance between hills within rows, to give a final plant density of 53 500 plants/ha.

From the experiment, data were recorded for days to 50% tasseling, plant height, cob height, percentage of root and stalk lodging, ear aspect, husk cover and field ear weight as well as grain moisture at harvest. Plots were hand-harvested and grain yield was calculated based on 80% shelling, and adjusted to 15% moisture. Except for 50% tasseling, these characteristics were measured just before or during harvesting. For husk cover, an ear tip tightly covered with husks was given a value of 1 while 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 a deformed and poorly filled ear a value of 5.

From the data obtained, heterosis and heterobeltoisis were calculated for grain yield, and expressed as the percentage deviation over mid-parent and over high-parent (Davis and Rutger 1976; Virmani et al. 1981). The procedure employed for combining ability analysis was based on Griffing's (1956) Method Two analysis. The procedure was used to analyse the general combining ability and specific combining ability estimates for all the traits measured or evaluated.

Results

Generally, the parental varieties were higher yielding than the crosses *(Table 2)*. Among the parents, Nakhorn Suwan 1 and Pop. 28 had the highest mean yields of 7 809 and 6 697 kg/ha respectively. Among the crosses, the mean yields ranged from 2 728 kg/ha (Bertam 8602 x Bertam 8701) to 7 051 kg/ha (Bertam 8701 x Suwan 3). Mid-parent heterosis ranged from –52.37% to 22.67% . Six hybrids showed positive heterosis, with values ranging from 0.08% to 22.67%. High-parent heterosis ranged from –54.66% (Bertam 8602 x Bertam 8701) to 22.35% (Bertam 8701 x Suwan 3). Only two crosses, viz. Bertam 8805 x Suwan 3 and Bertam 8701 x Suwan 3, showed positive heterosis of 11.73% and 22.35% respectively. Mean values for other plant characteristics are shown in *Table 2*.

Discussion and conclusion

Heterosis

Results of this study showed that the levels of heterosis obtained were low. In the studies of diallel crosses among CIMMYT's tropical and subtropical materials, low heterosis had also been reported (Beck et al. 1990, 1991; Crossa et al. 1990). In summarising 47 independent reports, Hallauer and Miranda (1981) found the mean high-parent heterosis for yield to be 8.2% from 1 394 varietal crosses involving 611 parental varieties. The low level of heterotic response was expected as the varieties were composited without considering the differences in heterotic patterns. Therefore, crosses of these broad-based varieties led to partial cancellation of heterotic effects resulting in a low or moderate level of mid-parent heterosis. In this study, however, a preponderance of crosses with negative heterosis was manifested. This effect was also found by other researchers (Yap and Tan 1974; Peng and Virmani 1991). However, Bertam 8805 x Suwan 3 and Bertam 8701 x Suwan 3 showed some potential, and are therefore good starting materials for initiating hybrid work.

Combining ability analysis

The variances due to general combining ability (GCA) were non-significant, but were

Table 2. Mean yield, yield heterosis (relative to the high-parent yield), days to 50% tasseling, and cob heights, husk cover and ear aspect of six best performing grain maize varieties and their crosses

Variety/cross	Yield (kg/ha)	Yield heterosis (%)	50% tasseling (days)	Plant height (cm)	Cob height (cm)	Husk* cover	Ear** aspect
Bertam 8805 x Bertam 8602	5 800	–3.60	51.7	202.2	97.2	3.00	2.00
Bertam 8805 x Bertam 8701	5 699	–2.98	50.0	216.2	107.8	1.67	1.33
Bertam 8805 x Pop. 28	6 604	–1.38	50.3	205.2	96.3	1.67	1.33
Bertam 8805 x Suwan 3	6 563	11.73	49.3	218.3	109.3	2.67	1.67
Bertam 8805 x Nakhorn Suwan 1	6 085	–22.08	51.7	207.4	95.6	2.33	1.33
Bertam 8602 x Bertam 8701	2 728	–54.66	53.7	177.8	83.3	3.00	4.00
Bertam 8602 x Pop. 28	6 574	–1.84	50.3	195.7	98.2	1.67	1.67
Bertam 8602 x Suwan 3	5 636	–6.33	50.7	195.2	89.1	1.00	1.67
Bertam 8602 x Nakhorn Suwan 1	6 505	–16.71	51.0	210.4	111.1	1.67	1.33
Bertam 8701 x Pop. 28	4 021	–39.96	52.7	197.0	93.6	3.00	2.67
Bertam 8701 x Suwan 3	7 051	22.35	51.3	208.2	106.3	1.33	1.33
Bertam 8701 x Nakhorn Suwan 1	6 852	–12.26	51.0	233.2	107.2	2.00	1.33
Pop. 28 x Suwan 3	3 584	–46.48	52.3	193.9	96.0	2.33	3.00
Pop. 28 x Nakhorn Suwan 1	5 489	–29.71	52.3	212.7	100.9	2.33	2.67
Suwan 3 x Nakhorn Suwan 1	4 128	–47.14	53.0	205.1	100.7	3.00	3.33
Overall crosses	5 554	–16.19	51.4	205.2	99.5	2.18	2.04
Bertam 8805	5 874	–	52.7	190.8	87.4	1.67	2.00
Bertam 8602	6 016	–	51.0	205.5	99.2	2.00	1.33
Bertam 8701	5 433	–	55.0	206.4	107.3	2.00	1.33
Pop. 28	6 697	–	52.3	216.5	106.2	1.67	1.00
Suwan 3	5 763	–	53.3	228.1	115.6	2.67	1.33
Nakhorn Suwan 1	7 809	–	52.0	227.8	114.4	2.33	1.33
Overall parent	6 265	–	52.7	212.5	105.0	2.06	1.39
SE/plot	1 296	–	1.0	16.7	10.7	0.64	0.74
C.V. (%)	22	–	2.0	8.1	10.5	29.78	39.93

*An ear tip tightly covered with husks is given a value of 1, and a badly exposed ear tip a value of 5
**A well-formed and fully filled ear is given a value of 1 while a deformed and poorly filled ear a value of 5

highly significant for specific combining ability (SCA) for yield and ear aspect traits *(Table 3)*. Thus, the dominant type of gene action is important in the control of these traits. The importance of non-additive type of gene action for the control of yield had also been determined in two earlier related studies (Abdul Wahab 1995a, b). However, studies by Yap and Tan (1974) indicated that yield was primarily under the control of additive gene action. Nevertheless, Beck et al. (1990, 1991) and Vasal et al. (1992) showed that the relative importance of additive and non-additive gene action varied over environment and varieties studied. For the trait 50% tasseling, both the GCA and SCA effects were highly significant, indicating the importance of both dominant and additive types of gene action in the control of this trait. For plant and ear heights, the GCA effects were significant but non-significant for SCA. For husk cover, the variances due to both GCA and SCA were non-significant.

- **General combining ability effects**
  Nakhorn Suwan 1 *(Table 4)* was the best general combiner for yield followed by Bertam 8805. For 50% tasseling, the two best combiners were Bertam 8701 and Suwan 3. Nakhorn Suwan 1 was also the best general combiner for plant and ear

Table 3. Analysis of variance of combining ability

Source	d.f.	Yield	50% tasseling	Plant height	Ear height	Husk cover	Ear aspect
GCA	5	955 968.00ns	1.66**	252.79*	92.92*	3.71ns	0.67ns
SCA	15	1 715 600.67**	1.92**	155.06ns	71.75ns	4.29ns	0.85**
Error	40	554 984.59	0.36	93.22	37.83	2.21	0.18

**significant at 1% level of probability
*significant at 5% level of probability

Table 4. Estimates of GCA effects for yield, 50% tasseling, plant and ear heights, husk cover and ear aspect for six varietal parents

Variety	Yield (kg/ha)	50% tasseling (days)	Plant ht. (cm)	Ear ht. (cm)	Husk cover	Ear aspect
Bertam 8805	274.42	–0.53	–2.52	–3.31	–0.04	–0.17
Bertam 8602	–128.71	–0.40	–7.37	–3.79	–0.08	0.04
Bertam 8701	–385.83	0.76	–0.75	0.66	0.00	0.04
Pop. 28	–79.67	0.01	–1.72	–1.25	–0.08	0.04
Suwan 3	–226.92	0.10	3.22	3.12	0.08	0.08
Nakhorn Suwan 1	546.71	0.06	9.14	4.58	0.13	–0.04
SE (g_i)*	241.52	0.19	3.12	1.99	0.12	0.14
SE of diff. ($g_i - g_j$)	374.16	0.30	4.83	3.08	0.18	0.21

*g_i 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

heights. Overall, the analyses indicated that Nakhorn Suwan 1 and Bertam 8805 were the best general combiners for yield and most other growth traits. Bertam 8805 showed small negative values for GCA for 50% tasseling as well as plant and ear heights, indicating negative heterosis for these traits in hybrids. Negative heterosis in these traits is actually selected for besides having positive heterosis for yield. The experimental results, therefore, indicate that Nakhorn Suwan 1 and Bertam 8805 might be good entries for the formation of a composite variety or as a source germplasm for the maize improvement programme.

- **Specific combining ability effects**

Out of the 15 crosses, seven showed positive effects for grain yield *(Table 5)*. The best three cross-combinations were Bertam 8701 x Suwan 3, Bertam 8602 x Pop. 28 and Bertam 8701 x Nakhorn Suwan 1. Good general combiners may not always produce good F_1 combinations. As observed in this study, Bertam 8805 and Nakhorn Suwan 1 had high GCA effects for yield but the hybrids obtained by crossing these parents exhibited negative effects. This observation was also true for other crosses and traits. Similar observations have also been made in rice (Singh et al. 1979). However, hybrids recording high SCA effects have been observed to have at least one parent with high GCA effect (Yuan and Virmani 1986; Bhanumathy and Prasad 1991).

For 50% tasseling, seven crosses showed positive SCA effects. Eight combinations showed negative SCA effects; three of which were significant, those being Bertam 8805 x Bertam 8701, Bertam 8805 x Suwan 3 and Bertam 8701 x Nakhorn Suwan 1. Six crosses showed positive SCA effects for plant height while nine crosses showed

Table 5. Estimates of SCA effects for yield, 50% tasseling, plant and ear heights, husk cover and ear aspect for 15 varietal crosses

Cross	Yield (kg/ha)	50% tasseling (days)	Plant height (cm)	Ear height (cm)	Husk cover	Ear aspect
Bertam 8805 x Bertam 8805	–432.55	1.98	–11.42	–7.04	–0.39	0.48
Bertam 8805 x Bertam 8602	–103.76	0.80	4.75	3.23	0.98	0.27
Bertam 8805 x Bertam 8701	52.70	–2.03	12.10	9.41	–0.43	–0.40
Bertam 8805 x Pop. 28	651.87	–0.95	2.17	–0.18	–0.35	–0.40
Bertam 8805 x Suwan 3	758.12	–2.03	10.34	8.39	0.48	–0.11
Bertam 8805 x Nakhorn Suwan 1	–493.84	0.35	–6.52	–6.77	0.11	–0.32
Bertam 8602 x Bertam 8602	516.04	0.01	12.89	5.68	0.02	–0.61
Bertam 8602 x Bertam 8701	–2 515.51	1.51	–21.36	–14.68	0.94	2.06
Bertam 8602 x Pop. 28	1 024.66	–1.07	–2.49	2.20	–0.31	–0.27
Bertam 8602 x Suwan 3	233.58	–0.82	–7.99	–11.34	–1.14	–0.32
Bertam 8602 x Nakhorn Suwan 1	328.95	–0.45	1.29	9.24	–0.52	–0.52
Bertam 8701 x Bertam 8701	447.29	1.68	0.56	4.93	–0.14	–0.61
Bertam 8701 x Pop. 28	–1 271.21	0.10	–7.84	–6.89	0.94	0.73
Bertam 8701 x Suwan 3	1 906.37	–1.32	–1.54	1.44	–0.89	–0.65
Bertam 8701 x Nakhorn Suwan 1	933.08	–1.61	17.51	0.85	–0.27	–0.52
Pop. 28 x Pop. 28	1 098.62	0.51	12.60	7.65	–0.31	–0.94
Pop. 28 x Suwan 3	–1 867.13	0.43	–14.90	–6.95	0.19	1.02
Pop. 28 x Nakhorn Suwan 1	–735.42	0.47	–2.16	–3.48	0.15	0.81
Suwan 3 x Suwan 3	459.12	1.35	14.33	8.28	0.36	–0.69
Suwan 3 x Nakhorn Suwan 1	–1 949.17	1.05	–14.56	–8.11	0.65	1.43
Nakhorn Suwan 1 x Nakhorn Suwan 1	958.28	0.10	2.22	4.13	–0.06	–0.44
SE of diff. ($S_{ii} - S_{jj}$)	748.32	0.60	9.65	6.15	0.37	0.43
SE of diff. ($S_{ij} - S_{ik}$)	989.94	0.80	12.77	8.14	0.49	0.57
SE of diff. ($S_{ij} - S_{kl}$)	916.50	0.74	11.82	7.53	0.45	0.52

*S_{ij} is the estimated 'extra' performance when line *i* is crossed with line *j*, in addition to that measured by g_i and g_j, compared with the overall mean.

negative effects, the highest of which were Bertam 8602 x Bertam 8701, Pop. 28 x Suwan 3 and Suwan 3 x Nakhorn Suwan 1. For ear height, seven hybrids showed positive SCA effects while eight showed negative effects. The three crosses with the highest negative values were Bertam 8602 x Bertam 8701, Bertam 8602 x Suwan 3 and Suwan 3 x Nakhorn Suwan 1.

Among the crosses studied, a few crosses had low magnitude of heterosis and none of the crosses surpassed the best parental variety, Nakhorn Suwan 1, in yield. Therefore, direct development of a hybrid variety based on any of the specific crosses is not feasible.

Besides the inclusion of recommended varieties from those evaluated as a component of composite varieties, there are other ways of using these varieties. Eberhart et al. (1967) proposed a comprehensive breeding programme. It involves the development of two breeding populations exhibiting considerable heterosis when crossed and yet retaining adequate genetic variation to permit rapid progress from recurrent selection. These initial populations for such a reciprocal recurrent selection programme are usually selected based on their yield performance and the average of their crosses (Hallauer and Miranda 1981) without giving special attention to specific effects. Thus, Nakhorn Suwan 1 and Pop. 28 would be selected. In this study however, the effect of SCA was significant and should not be ignored. Bertam 8701 and Suwan 3 therefore, should, also be selected as the cross showed significant positive SCA effects for yield.

Results of the trials can also be used to develop two breeding populations, each one being a composite of several others, that will give considerable heterosis when crossed (Eberhart et al. 1967). With this approach, the genetic basis of the foundation populations for the selection programme is greatly enhanced, while their inbreeding level is minimised. To maximise heterosis, compositing should be done considering the similarity or dissimilarity among the varieties to be composed. Heterosis is a measure of global dissimilarity between any two operational taxonomic units. Non-segregating characteristics will not contribute to heterosis. In fact, heterosis can be a measure of genetic relationship as opposed to coefficients that measure only phenetic relationships like Euclidean distance. Phenograms using the unweighted pair groups method which employs arithmetic averages, with mid-parent heterosis for yield as the measure of dissimilarity can be constructed. These phenograms are used to divide the varieties into 2–3 clusters or populations (Rhomesburg 1984). Each cluster will be used subsequently to compose a composite.

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