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Performance and Yield Predictions in Double Cross Hybrids of Tropical Grain Maize

SRIANI SUJIPRIHATI[1], GHIZAN SALEH[2] & ELTAHIR SIDDIG ALI[2]

[1] *Centre for Crop Improvement Studies, Bogor Agricultural University, Indonesia*

[2] *Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia 43400 UPM, Serdang, Selangor, Malaysia*

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ABSTRAK

Penggunaan hibrid kacukan dua ganda dalam jagung disarankan dalam keadaan terdapatnya masalah pengeluaran biji benih sekiranya kacukan tunggal digunakan, kesan dari kecergasan dan hasil rendah yang diberikan oleh induk-induk inbrednya. Hibrid kacukan dua ganda diketahui boleh menunjukkan prestasi yang agak baik dalam keadaan persekitaran yang pelbagai. Sebagai sebahagian daripada program pembiakbakaan jagung bijian yang sedang dijalankan di Universiti Putra Malaysia, titisan-titisan inbred yang berprestasi tinggi telah dipilih dan dikacukkan untuk menghasilkan kacukan-kacukan tunggal. Kacukan-kacukan tunggal ini seterusnya digunakan untuk membentuk beberapa hibrid kacukan dua ganda. Dalam kajian ini, prestasi sepuluh hibrid dua ganda terpilih telah dinilaikan pada dua persekitaran di kawasan penyelidikan Universiti Putra Malaysia. Prestasi ramalan hibrid kacukan dua ganda ini juga dibandingkan dengan prestasi sebenar menggunakan kaedah berdasarkan nilai-nilai yang ditunjukkan oleh kacukan tunggal bukan induknya. Hibrid kacukan dua ganda yang memberikan prestasi terbaik, DC-26 dan DC-34 didapati memperoleh hasil yang tinggi di tiap-tiap daripada dua persekitaran serta juga dalam analisis gabungan. DC-26 dan DC-34 masing-masing memberikan purata hasil bijian sebanyak 6125.0 dan 5917.8 kg/ha di Ladang 2, masing-masing 5648.9 dan 5676.2 kg/ha di Ladang Kongsi, dan masing-masing 5887.0 dan 5797.0 kg/ha di dalam analisis gabungan. Daripada keputusan analisis korelasi, kedua-dua prestasi sebenar dan prestasi ramalan untuk hibrid-hibrid dua ganda ini didapati selari antara satu dengan lain di tiap lokasi dan lokasi gabungan ($r = 0.38$, 0.46 and 0.27, masing-masing di Ladang 2, Ladang Kongsi dan gabungan kedua-dua lokasi), membuktikan bahawa kaedah yang digunakan untuk ramalan hasil dalam hibrid-hibrid tersebut adalah sesuai.

ABSTRACT

The use of double cross hybrids in maize was suggested to overcome the problem of seed production related to single cross resulting from low vigor and yield associated with the inbred parents. Double cross hybrids were known to perform quite well under a wide range of environmental conditions. As a part of an ongoing grain maize improvement program at Universiti Putra Malaysia, the best performing inbred lines were selected and crossed to produce single crosses. These single crosses were further used to produce some double cross hybrids. In this study, the performance of ten selected double cross hybrids was evaluated at two environments in the research areas of Universiti Putra Malaysia. The predicted performance of these double cross hybrids was also compared with the actual, using the method based on the mean values of non-parental single crosses. The best performing double cross hybrids, DC-26 and DC-34 were found to have high yields at both environments as well as in the combined analysis. DC-26 and DC-34 gave mean grain yields of 6125.0 and 5917.8 kg/ha respectively, at Field 2, 5648.9 and 5676.2 kg/ha respectively, at Share Farm, and 5887.0 and 5797.0 kg/ha respectively, in the combined analysis. From the correlation analysis, the actual and the predicted performances of the double cross hybrids were found to be in good agreement at each location and locations combined ($r = 0.38$, 0.46 and 0.27, respectively, at Field 2, Share Farm and at the two locations combined), implying that the method used for yield predictions in the crosses was appropriate.

INTRODUCTION

In Malaysia, local production of grain maize is encouraged to minimize the cost of importing animal feed from abroad. The seed production of single cross hybrids faces some constraints as a consequence of low vigor and yield of inbred parents after the successive selfing process at the early generations. To overcome this, Jones (1918, 1922) suggested the use of double cross hybrids in maize. A double cross hybrid results from the cross between two single crosses that are themselves the result of crosses between two selected inbred lines (Hallauer and Miranda 1982). For successful double cross hybrid development, heterotic effects have to be maximized, and the best results are expected when four unrelated or diverse inbred lines are used.

Although double cross hybrids show slightly higher variation in plant and ear characters as compared to single crosses, which might affect the grain yield, the cost of seed production could be reduced because they are produced on single cross hybrids as parents, which produce more seeds compared to inbred parents, as in the case of single cross hybrids (Jugenheimer 1976; Stoskopf *et al.* 1993).

Testing and selection of superior inbred lines for their combining ability for hybrid production demands a great amount of effort. When a high number of inbred lines are tested, the possible number of hybrid combinations to be evaluated is tremendously high. This poses a lot of practical difficulties in conducting extensive yield tests. Therefore, with the ability to accurately predict the performance of double cross hybrids from the performance of single crosses, only promising double crosses need to be developed and the yield performance confirmed in actual yield tests. This would effectively facilitate double cross hybrid development.

Several methods of making predictions of performance of double cross hybrids based on performance of single crosses were proposed. However, the most accurate prediction was found to be the mean value of the four non-parental single crosses (Allard 1970).

The main objectives of this study were to evaluate the performance of some double cross hybrids developed from previously selected highly potential single crosses, and to compare their performance with the predicted ones.

MATERIALS AND METHODS

Ten double cross hybrids developed from eleven inbred lines originating from five different source populations were used in this study. Experiments were conducted using the open-pollinated varieties, Suwan 1, Suwan 3 and Metro functioned as checks at two locations, Field 2 and Share Farm, Universiti Putra Malaysia.

The double crosses were formed on the basis of the performance of their respective single crosses revealed earlier (Sujiprihati 1997). Double crosses D-26, D-27 and D-28 were formed from two high single cross performers; D-29, D-30, D-31 and D-32 were formed between high and medium single cross performers, while D-33, D-34 and D-35 were the double crosses formed from two medium single cross performers.

The experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications. The planting density used was 0.75 X 0.25 m. In each replication, plants were grown in 5-m long, 5-row plots, where the middle three rows (4 m in length) were used as harvested area. The experiments were conducted under standard cultural practices. Characters measured include:

a. Pre-harvest characters:
   1. Plant height at tasseling (cm)
   2. Days to tasseling (days)
   3. Days to maturity (days)

b. Post-harvest characters:
   1. Grain yield (kg/ha)
   2. Ear weight (g)
   3. Grain weight/ear (g)
   4. 100-grain weight (g)
   5. Shelling percentage.

The analysis of variance (ANOVA) was applied to the double cross performance data, where sample means in each plot were used for most of the characters studied except for grain yield, and flowering and maturity characters, where plot values were used. The analysis of variance was carried out using the Statistical Analysis System (SAS) computer package (SAS Institute Inc. 1991).

Predicted performance of the double cross hybrids was calculated on the basis of average performance of the non-parental single crosses from data obtained by Sujiprihati (1997), and

using the formula by Allard (1970) as follows: Predicted performance of double cross =

$$[(A \times C) + (A \times D) + (B \times C) + (B \times D)] / 4;$$

where A, B, C and D are inbred lines involved in a double cross (A X B) X (C X D).

For all characters studied, simple phenotypic correlations between actual and predicted performances of double cross hybrids were computed and their significance was determined using the t-test.

RESULTS

From results of the test of homogeneity of error variances (Table 1), error variances were found to be homogeneous for all characters except for ear weight, grain weight per ear and shelling percentage. Therefore, results from the combined analysis applied and are relevant.

Significant effects of locations were observed only for grain yield, grain weight/ear, 100-grain weight and plant height (Table 2), indicating that variations between the two locations only affected these traits. Significant effects of genotypes were shown for all characters studied at each location and locations combined, except for ear weight, grain weight/ear and shelling percentage at Field 2, and grain yield, ear weight and plant height at Share Farm.

The mean values for performance of the double cross hybrids for all characters were presented in Tables 3 to 5 for each of the two locations and locations combined. The best performing double cross hybrid at Field 2 was DC-26 which yielded (6125.0 kg/ha), followed by DC-34 and DC-29 with mean grain yields of 5917.8 and 5802.6 kg/ha, respectively. These values were higher than the two check varieties Suwan 3 and Metro, but not significantly different from Suwan 1 (Table 3). At Share Farm, the leading double cross hybrids were DC-26 and DC-34, with mean grain yields of 5648.9 and 5676.2 kg/ha, while for locations combined the two hybrids gave average grain yields of 5887.0 and 5797.0 kg/ha, respectively (Tables 4 and 5). These values were significantly higher than the three check varieties used. The two double cross hybrids, DC-26 and DC-34 were superior for all yield components, in particular at Field 2 and the locations combined.

From results shown in Table 6, the predicted grain yields of the double cross hybrids were found to be lower than the actual, but the relative trends were in good agreement, with significant correlation coefficients between the actual and predicted being 0.38, 0.46 and 0.27, respectively at Field 2, Share Farm and the locations combined. The correlation coefficients between the actual and the predicted performances were in general significant for other characters at both locations and locations combined. Exceptions were, however, shown by ear weight, grain weight/ear and shelling percentage at Field 2, and grain weight/ear and shelling percentage at Share Farm and the combined analysis, which showed non-significant correlations.

DISCUSSION

It was clearly seen from the results that the hybrids responded quite similarly at the two locations, and the variances were quite homogeneous. Average yield superiority of the

TABLE 1
Test of homogeneity of error variances from the ANOVA on performance of double cross maize hybrids between locations

Character	Error Mean Squares		F calculated
	At Field 2	At Share Farm	
Grain yield	196285.77	277256.10	1.41
Ear weight	269.53	110.79	2.43*
Grain weight /ear	207.05	97.33	2.12*
100-grain weight	3.65	3.41	1.07
Shelling percentage	8.77	3.28	2.68*
Plant height	228.57	275.92	1.21
Days to tasseling	1.14	1.40	1.23
Days to maturity	0.89	1.22	1.38

* Significant at $p \leq 0.05$

TABLE 2
Mean squares for characters measured on double cross maize hybrids at each of the two locations and locations combined

Source of variation	d.f.	Grain yield	Ear weight	Grain weight/ear	100-grain weight	Shelling percentage	Plant height	Days to tasseling	Days to maturity
At Field 2:									
Blocks	2	366193	1038*	652	8.77	6.30	135	0.03	4.39*
Genotypes	12	757405**	569	437	13.93**	14.35	786**	13.02**	8.17**
Error	24	196286	270	207	3.65	8.78	229	1.14	0.88
At Share Farm:									
Blocks	2	70970	25	40	19.02*	1.31	1916**	29.56**	0.31
Genotypes	12	464997	184	261*	12.26**	18.24**	507	10.26**	8.03**
Error	24	277256	111	97	3.41	3.28	276	1.40	1.22
At Locations Combined:									
Locations	1	900285*	662	663*	207.80**	21.29	438	7.39	1.85
Blocks/Location	4	218582	532*	346	13.90**	3.80	1025**	14.80**	2.35
Genotypes	12	1109479**	589**	559**	22.28**	23.46**	1120**	21.67**	14.51**
Pooled Error	60	212002	185	150	3.60	6.65	236	1.34	1.18

* Significant at $p \leq 0.05$
** Significant at $p \leq 0.01$

TABLE 3
Mean values for characters measured on double cross maize hybrids and check varieties, at Field 2

Double cross/ Check variety	Grain yield (kg/ha)	Ear weight (g)	Grain weight/ear (g)	100-grain weight (g)	Shelling percentage (%)	Plant height (cm)	Days to tasseling (days)	Days to maturity (days)
Double cross:								
DC-26	6125.0	175.3	152.8	30.3	87.8	187.7	51.7	93.3
DC-27	4504.9	130.0	114.0	26.4	88.2	179.4	58.0	94.7
DC-28	5135.2	155.5	134.2	25.9	86.2	180.1	54.0	95.3
DC-29	5802.6	156.0	134.4	27.1	86.2	172.1	51.3	91.7
DC-30	4449.0	129.6	111.8	23.6	86.4	153.8	53.7	95.3
DC-31'	5437.6	151.7	133.5	29.0	90.6	194.9	52.7	95.7
DC-32	5432.8	152.0	130.9	28.8	86.9	178.8	53.7	93.7
DC-33	5193.4	161.9	138.4	30.0	85.5	185.1	54.7	95.7
DC-34	5917.8	173.0	146.9	29.1	84.7	179.5	55.0	96.3
DC-35	5422.2	152.7	127.6	27.9	83.2	178.3	53.3	93.7
Check variety:								
Suwan 1	5341.5	139.1	115.3	30.3	83.3	193.1	55.0	95.3
Suwan 3	4884.5	148.4	128.4	31.6	86.6	180.5	52.3	96.0
Metro	4984.5	152.0	126.2	28.4	82.8	225.8	58.0	98.3
LSD (0.05)	746.6	27.7	24.3	3.2	5.0	25.5	1.8	1.6
c.v. (%)	8.4	10.8	11.0	6.8	3.4	8.2	2.0	1.0

TABLE 4
Mean values for characters measured on double cross maize hybrids and check varieties at Share Farm

Double cross/ Check variety	Grain yield (kg/ha)	Ear weight (g)	Grain weight/ear (g)	100-grain weight (g)	Shelling percentage (%)	Plant height (cm)	Days to tasseling (days)	Days to maturity (days)
Double cross:								
DC-26	5648.9	147.5	123.7	32.0	84.1	176.7	52.0	93.0
DC-27	4470.4	134.9	114.1	31.5	84.0	164.9	56.0	94.7
DC-28	5021.9	151.7	133.1	29.7	87.9	181.2	53.0	95.3
DC-29	4970.5	143.5	122.9	29.7	85.7	170.8	51.7	94.3
DC-30	4625.9	135.9	114.2	29.5	84.2	160.4	54.3	94.7
DC-31'	5455.4	153.5	135.0	29.9	88.0	189.6	51.3	96.0
DC-32	5410.4	150.0	128.4	32.3	85.6	184.1	51.3	94.0
DC-33	5107.9	149.7	127.6	31.3	85.2	177.4	53.0	94.3
DC-34	5676.2	160.8	141.1	31.8	87.7	191.1	53.0	95.7
DC-35	5134.4	146.5	129.8	29.3	86.9	157.4	53.7	94.7
Check variety:								
Suwan 1	4862.4	147.3	119.5	33.8	80.7	185.9	54.3	96.7
Suwan 3	4868.8	143.5	121.4	35.9	84.6	185.4	53.0	96.0
Metro	4585.0	134.0	107.9	33.7	80.3	202.7	57.7	99.7
LSD (0.05)	887.3	17.7	16.6	3.1	3.1	28.0	2.0	1.9
c.v. (%)	10.4	7.2	7.9	5.9	2.1	9.3	2.2	1.2

TABLE 5
Mean values for characters measured on double cross maize hybrids and check varieties, at the two locations combined

Double cross/ Check variety	Grain yield (kg/ha)	Ear weight (g)	Grain weight/ear (g)	100-grain weight (g)	Shelling percentage (%)	Plant height (cm)	Days to tasseling (days)	Days to maturity (days)
Double cross:								
DC-26	5887.0	161.4	138.2	31.0	86.0	182.2	51.8	93.2
DC-27	4487.6	132.5	114.1	29.0	86.1	172.1	57.0	94.7
DC-28	5078.5	153.6	133.6	27.8	87.1	180.6	53.5	95.3
DC-29	5386.6	149.8	128.7	28.4	85.9	171.5	51.5	93.0
DC-30	4537.5	132.8	113.0	26.5	85.3	157.1	54.0	95.0
DC-31'	5446.5	152.6	134.3	29.4	89.3	192.3	52.0	95.8
DC-32	5421.6	151.0	129.6	30.6	86.3	192.3	52.5	93.8
DC-33	5150.7	155.8	133.0	30.7	85.4	181.5	53.8	95.0
DC-34	5797.0	166.9	144.0	30.4	86.2	181.3	54.5	96.0
DC-35	5278.3	151.1	128.7	28.6	85.0	167.9	53.5	94.2
Check variety:								
Suwan 1	5102.0	143.2	117.4	32.1	82.0	189.5	54.7	96.0
Suwan 3	4876.7	146.0	124.9	33.8	85.6	182.9	52.7	96.0
Metro	4784.9	143.0	117.1	31.0	81.5	205.4	57.8	99.0
LSD (0.05)	564.9	16.0	14.3	2.2	2.9	18.4	1.3	1.2
c.v. (%)	9.4	9.2	9.7	6.3	2.9	8.8	2.1	1.1

TABLE 6
Predicted and actual performance of double cross hybrids and their correlations at each of the two locations, and locations combined

Performance	Grain yield (kg/ha)	Ear weight (g)	Grain weight/ear (g)	100-grain weight (g)	Shelling percentage (%)	Plant height (cm)	Days to tasseling (days)	Days to maturity (days)
At Field 2:								
Predicted	3402.0	129.3	99.1	27.4	82.0	160.8	51.9	92.3
Actual	5342.1	148.6	132.5	27.8	86.6	179.0	53.8	94.5
Correlations (r)	0.38*	0.23	0.01	0.36*	0.09	0.40*	0.56**	0.44*
At Share Farm:								
Predicted	4699.0	131.4	100.9	28.9	82.0	172.5	52.0	91.5
Actual	5152.2	147.7	127.7	30.7	85.9	175.4	53.0	94.7
Correlations (r)	0.46*	0.40*	0.26	0.37*	0.28	0.45*	0.62**	0.36*
At Locations Combined:								
Predicted	4217.0	130.4	100.0	28.2	82.0	166.7	56.5	91.9
Actual	5226.1	148.1	130.1	29.2	86.2	177.2	58.0	94.6
Correlations (r)	0.27*	0.25*	0.09	0.54**	0.16	0.33*	0.58**	0.39*

* Significant at $p \leq 0.05$
** Significant at $p \leq 0.01$

double cross hybrids over the check varieties was shown with particularly excellent performance of DC-26 and DC-34. With their high yielding capability (5 to 6 tons/ha) and early maturity, these double cross hybrids are promising with good potential use in commercial production. The average yields of these hybrids were higher than the average productivity of the presently available open-pollinated varieties, and as high as that of the local single cross hybrid variety, Putra J-58, which was found to give grain yield 6.2 tons/ha (Saleh 1998). Although only two locations were used in this study, double cross hybrids were proven capable of performing well in a wide range of environments as reported by Eberhart and Russell (1969) and Weatherspoon (1970).

The method used for yield prediction was satisfactory and was supported by results from previous research workers such as Eberhart and Hallauer (1968); Zuber *et al.* (1973) and Moll and Stuber (1974). There were strong correlations between the predicted and actual performances of the hybrids at both locations and in the combined analysis as indicated by the significant correlation coefficients for most of the characters.

The results of this study on yield prediction were strengthened and advocated by reports from Otsuka *et al.* (1972) and Stuber *et al.* (1973), showing that preliminary selections for double cross hybrids can be efficiently performed by utilizing predictions based on non-parental single cross means obtained from a number of environments. Furthermore, the final evaluation of a reduced number of selected hybrids require sufficient environments to verify hybrids' suitability for commercialization. The information obtained on performance of the non-parental single crosses in this study was, therefore, effective in predicting performance of the double cross hybrids from a selected group of inbred lines. However, it suggested that the appropriate single crosses should be evaluated in preliminary field trials at several locations.

CONCLUSION

Results of this study on actual yield, as well as yield predicted based on the average performance of the non-parental single crosses, had reflected the superiority of the two double cross hybrids DC-26 and DC-34 over the check varieties. Thus, they could be suggested for further testing in larger scale evaluation trials towards their use in commercial production in this country.

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