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RELATIVE PERFORMANCE OF TESTERS TO IDENTIFY ELITE LINES OF CORN (*Zea mays* L.)[1]

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ABSTRACT - Testcross evaluation is used to determine the relative potential of corn (*Zea mays* L.) lines in a hybrid breeding program. Choice of tester is important for efficient selection among lines for their potential in hybrids. Testcrosses among 21 lines and seven testers were evaluated at seven environments in Guatemala. The experimental design was a randomized complete block with a split-plot arrangement, where lines were assigned to whole plots and testers to subplots. The objectives of the study were to obtain information for choice of testers and to identify the more convenient tester to use in early testing for a hybrid program in which three-way and double-cross hybrids are commonly used. Data for yield and agronomic traits were recorded, but the combined analysis for yield (t/ha) was the main trait of interest. Differences among lines and among testers across environments were highly significant ($P \leq 0.01$). Highly significant differences for the testers x lines interaction indicated that the testers ranked the lines differently. Coefficient of concordance (W) and Pearson correlations (r) suggested that the ranking of lines across testers was relatively consistent. Testcrosses with a single cross had the greatest average yield (6.48 t/ha). Based on the variance among testcrosses, estimates of general combining ability, correlation with the other testers, and acceptable performance itself, the single cross tester was suggested as the tester for the hybrid breeding program in Guatemala. Lines with good general combining ability for different hybrid combinations were identified. Three-way testcrosses superior to the best check (ICTA HB-85) were identified for further evaluation as potential new hybrids for release. Significant correlations between yield and diseases (Southern corn rust caused by *Puccinia polysora* Underw. and Northern corn leaf blight caused by *Exserohilum turcicum* Pass. = *Helminthosporium turcicum* Pass.) reflected the importance of emphasizing selection for disease resistance during line development.

KEY WORDS: *Zea mays* L.; Maize; Testers; Testcrosses; Combining ability; Disease resistance.

INTRODUCTION

Corn (*Zea mays* L.) hybrid development has been an important factor in meeting the increasing world demand of this cereal during the past 30 years. Although there are countries in which corn hybrids are not the main cultivars used, national and private breeding programs are providing resources for hybrid development as an alternative to increase corn production either for domestic consumption or for trading in the world market.

Different studies have provided definitions of either the best or the more convenient tester (MATZINGER, 1953; RAWLINGS and THOMPSON, 1962; ALLISON and CURNOW, 1966; HALLAUER, 1975; HALLAUER *et al.*, 1988). MATZINGER (1953) defined a convenient tester as one that combines simplicity in use with the maximum information on the performance among the lines when they are tested in other combinations or in other environments. RUSSELL (1961) concluded that the expression of greater genetic differences among testcrosses is one of the main features of an ideal tester parent. SMITH (1986) concluded that, if a tester with low frequency (or absence) of favorable alleles is used in the testcrosses, those lines with greater frequency of favorable alleles can be identified. HALLAUER (1975) and GENTER (1963) emphasized that elite lines in hybrid combinations should be obtained from simultaneous selection for disease and insect resistance and for agronomic traits. HALLAUER and MIRANDA (1988) summarized that either a homozygous recessive line or a population with low allele frequency for important traits under selection would be

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TABLE 1 - *Pedigree and level of inbreeding of 21 corn lines crossed to seven testers for evaluation in Guatemala.*

Pedigree of lines and level of inbreeding			
Line 1 Pop. 32 (S_1)-1408	Line 7 Pop. 32 (S_3)-1414	Line 13 Pop. 29 (S_5)-1420	Line 19 Achap. (S_4)-1426
Line 2 Pool 23 (S_1)-1409	Line 8 Pop. 32 (S_3)-1415	Line 14 Pop. 29 (S_5)-1421	Line 20 Achap. (S_3)-1427
Line 3 Pool 23 (S_2)-1410	Line 9 Pop. 21 (S_3)-1416	Line 15 Pop. 22 (S_5)-1422	Line 21 Pop. 22 (S_5)-1428
Line 4 Pop. 21 (S_2)-1411	Line 10 Pop. 22 (S_5)-1417	Line 16 Pop. 29 (S_5)-1423	
Line 5 Pop. 21 (S_1)-1412	Line 11 Pop. 22 (S_5)-1418	Line 17 Pop. 29 (S_5)-1424	
Line 6 Pop. 23 (S_1)-1413	Line 12 Pop. 22 (S_5)-1419	Line 18 Achap. (S_6)-1425	
Pedigree of testers			
Tester 1 GB-39 x GB-37	Tester 3 43-46 x GB-12	Tester 5 43-68 x GB-13	Tester 7 = GB-39
Tester 2 GB-39 x GB-13	Tester 4 43-46 x 43-68	Tester 6 Syn. ICTA B-1	

an effective tester to use in a hybrid breeding program. The choice of tester, however, usually involves several alternatives, such as broad genetic-base vs. narrow genetic-base, high allele frequency vs. low allele frequency, general combining ability vs. specific combining ability (SPRAGUE and TATUM, 1942), high yield vs. low yield, and several testers vs. one tester.

The objectives of this study were to obtain information among testers for evaluating lines in a Guatemala hybrid breeding program; to determine the relative performance of different testers in ranking a specific set of lines from different origins; and to identify the most convenient tester for evaluating lines for a hybrid breeding program in which three-way and double-cross hybrids are more commonly used.

MATERIALS AND METHODS

Materials

The germplasm included in this study was from the germplasm bank of the Instituto de Ciencia y Tecnología Agrícola (ICTA, Guatemala), which is the national institution for agriculture research in Guatemala. Twenty-one lines with different levels of inbreeding were crossed to seven testers with tropical adaptation to produce 147 testcrosses for evaluation (Table 1). Lines 1 to 17 and line 21 were developed from different populations and pools from the International Maize and Wheat Improvement Center (CIMMYT) located in Mexico. Lines 18 to 20 were developed from commercial materials that had some tolerance to corn stunt (*Spiroplasma kunkelii*) (WHITCOMB *et al.*) disease. Testers 1 to 5 are single crosses of materials with different levels of inbreeding; tester 6 is a synthetic cultivar, and tester 7 is an inbred line.

The 147 testcrosses (21 lines crossed to each of the seven testers) were the basic materials for the study. The seven testers themselves and seven commercial or experimental checks were included in each trial. The seven checks included ICTA HB-83M, ICTA HB-35, ICTA HB-87, ICTA HB-83MD, AGROMER HS-3G1, TACSA Exp., and DEKALB Exp. The checks identified as ICTA are hybrids from ICTA research, and the other three checks are hybrids from private companies marketing seed in Guatemala. Each experiment, therefore, included 161 entries: 147 testcrosses, seven testers, and seven checks.

The 147 testcrosses were produced in 1989 under irrigation at the Cuyuta Experiment Station. To obtain the seed of each of the 147 testcrosses, a plot of each line and each tester was planted. During pollination, pollen was collected and mixed from all plants of a line and applied to at least 15 ears of each of the seven testers. A bulk of kernels from all the ears of each specific line x tester cross was utilized for evaluation.

Evaluation Trials

Seven experiments of 161 entries were conducted. Each experiment had two replications. The experimental design was a randomized complete block design with a split-plot arrangement. The 23 whole plots included one whole plot of seven testcrosses for each of the 21 lines, a whole plot that included the seven testers, and a whole plot that included the seven checks. The split plots of the 21 lines were the seven testers.

The main (whole) experimental unit was a 14-row plot of testcrosses including each line crossed to the seven testers. For the split plots, the experimental unit was a two-row plot. Rows were spaced 75 cm apart and hills of two plants were spaced 50 cm within 5.5 m-long rows. Three seeds per hill were sown by hand planting. Plots were thinned to two plants per hill at a plant height of about 15 cm for a final stand of 22 plants (11 hills) per row. The split-plot experimental unit included a maximum of 44 plants (2 rows) in an area of 8.25 m^2 (5.5 m. x 0.75 m. x 2), for a stand of 53,333 plants/ha. Fertilization, weed control, and cultivation practices used at each location were based on conventional requirements and previous research experiences. All plots were hand harvested.

The evaluation trials were conducted at five locations in Guatemala during 1989 and 1990. Four experiments were sown during the rainy, commercial season (May-October) in 1989 at the San Jerónimo, Cuyuta, La Máquina, and Las Vegas locations. Three experiments were conducted under irrigation conditions during 1990 at the San Jerónimo, Cuyuta, and Zacapa locations. The five locations had different climatic conditions, and different climatic conditions occurred at the same location in different seasons. The 7-year/location combinations were designated as seven environments, which were located between 63 and 1,000 m altitude; this range is considered the tropical lowlands of Guatemala.

Data were recorded for 11 traits for each of the seven environments: yield (t/ha at 15.0% moisture), stand, days from planting to 50% silk emergence, plant height (cm), ear height (cm), grain moisture (%), husk cover (%), root lodging (%), stalk lodging (%), prolificacy, and ear rot. Some disease data also were taken at each location depending upon the level of disease development for each environment.

TABLE 2 – *Mean squares, means, and C.V. for yield (t/ha) from analysis of variance of 147 testcrosses between 21 lines and seven testers of corn evaluated at seven environments in Guatemala.*

Source of variation	d.f.	Environments[a] 1	2	3	4	5	6	7
Replications (R)	1	25.53**	0.63ns	12.23**	0.02ns	0.59ns	26.19**	2.80ns
Lines (L)	20	9.25**	1.06ns	3.45**	8.52**	5.81**	2.54ns	3.40**
Error (a)	20	1.34	2.36	0.62	1.29	1.89	1.83	1.82
Testers (T)	6	15.5**	0.99ns	3.38**	8.19**	19.09**	4.68**	2.05ns
L x T	120	2.11**	0.90ns	0.21ns	0.86ns	4.50**	1.11**	1.13**
Error (b)	126	0.59	0.98	0.19	0.73	0.62	0.32	0.56
Total	293							
Yield mean		7.53	6.03	1.86	5.12	7.99	6.74	7.35
Yield mean best tester[b]		8.28	6.21	2.17	5.74	8.62	7.09	7.56
Yield mean best three testcrosses		10.11	7.43	3.39	7.75	11.05	8.29	8.91
Yield mean best two checks		8.98	6.30	2.51	5.62	9.12	7.54	7.56
C.V. (%)		10.20	16.40	23.60	16.70	9.90	8.30	10.20

[a] ns, *, ** indicate no significance, and significance at the 0.05 and 0.01 probability levels, respectively.
[b] Tester = mean of all the crosses for the best tester.

Statistical Procedures

Analysis of variance (ANOVA) for yield (t/ha) was conducted for each of the seven environments, and a combined ANOVA was performed across the seven environments. For the combined ANOVA, only data of the 147 testcrosses (line x tester) were included because only these entries fit the requirement of a split plot arrangement The 14 entries that included the seven testers and the seven checks were analyzed separately as a randomized complete block design with two replications, using this information as a reference to make comparisons with the testcrosses. For the ANOVA of the testcrosses, environments and replications were considered as random effects, while lines and testers were considered as fixed effects. ANOVA for yield (t/ha) was conducted for each tester across environments because one of the main criterion for choosing a convenient tester is based on the variance among the testcrosses for each tester.

The source of variation for testers was partitioned in orthogonal contrasts to estimate the significance of contrasts among testers. Rank correlations for yield (t/ha) were estimated for testers and lines with the method proposed by KENDALL and SMITH (1939) as cited by OSTLE (1956). They proposed the concept of rank correlation for use when we have n individuals that are ranked from 1 to n for some specified characteristics by m observers. The rank correlation by KENDALL and SMITH (1939) was proposed as a measure known as the coefficient of concordance (W), which is defined by $W = 12S/m^2(n^3\text{-}n)$, where S equals the sum of squares of the deviations of the totals of the ranks assigned to each individual. W varies from 0 to 1, with 0 representing no common preference, whereas unity represents perfect agreement among m observers.

Pearson correlation coefficients for yield (t/ha) were estimated to determine the correlation between testcrosses for each pair of testers and between testcrosses for each tester and the mean of testcrosses across all testers. Yield mean (t/ha) for each testcross was obtained over environments to calculate general combining ability estimates for each line and for each tester.

Yield of the best 10 testcrosses, based on the combined analysis, was compared for each environment as well as their ranking in each environment. The objective of the comparisons of yield and rank among environments was to determinate variation in response among environments and to identify potential crosses that have stable performance across environments.

Entry identification used for each experiment is as follows: Entries 1 to 147 are for the testcrosses; Entry 148 is GB-39 x GB-37; Entry 149 is GB-39 x GB-13; Entry 150 is 43-46 x GB-12; Entry 151 is 43-46 x 43-69; Entry 152 is 43-68 x 43-68; Entry 153 is Syn. ICTA B-1; Entry 154 is GB-39; Entry 155 is HB-83; Entry 156 is HB-85; Entry 157 is HB-87; Entry 158 is HB-83MD; Entry 159 is HS-3G1; Entry 160 is TACSA; Entry 161 is DEKALB.

RESULTS AND DISCUSSION

The mean yield among environments varied from 1.86 t/ha (environment 3) to 7.99 t/ha (environment 5), reflecting the large differences in grain yield among environments (Table 2). Environment 3 was severely affected by dry conditions, and environment 5 was under optimum irrigation conditions. Environments 1 and 5 were at the same location, but environment 1 was under natural rainfall; difference in yield between environments 1 and 5 was 0.46 t/ha.

Tester 5 had the best average testcross yield at environments 1, 2, 4, and 5, and it was similar to the best tester at the other three locations. For individual environments, the mean yield of the best three testcrosses was significantly ($P \leq 0.05$) greater than the mean yield of the best two checks. The source of variation among testers was significantly different at five of the seven environments. The first-order interaction *(L x T)* mean square was less than the mean squares of the main effects of lines and testers in all instances. Line x tester interactions

TABLE 3 - *Mean squares, means, and C.V. for yield (t/ha) from the combined analysis of variance of 147 testcrosses between 21 lines and seven testers of corn across seven environments in Guatemala.*

Source of variation		d.f.	Mean squares[a]
Environments (E)		6	1298.86**
Replications/E		7	9.71**
Lines (L)		20	11.96**
L x E		120	3.68**
Error a		140	1.59
Testers (T)		6	26.47**
Contrast 1, 2, 3, 4, 5 vs. 6, 7		(1)	0.01ns
Contrast 6 vs. 7		(1)	42.68**
Contrast 1, 2 vs. 3, 4, 5		(1)	12.20ns
Contrast 1 vs. 2		(1)	0.00ns
Contrast 3 vs. 4, 5		(1)	100.23**
Contrast 4 vs. 5		(1)	3.66ns
T x E		36	3.74**
L x T		120	4.57**
L x T x E		720	1.04**
Error (b)		882	0.57
Total		2057	
Yield mean			6.09
Yield mean best tester[b]	(tester 5)		6.48
Yield best three testcrosses	(line 13 x tester 5)		7.38
	(line 14 x tester 4)		7.32
	(line 4 x tester 5)		7.28
Yield best two checks	(ICTA HB-85		6.35
	(DEKALB)		6.23
C.V. (%)			12.40

[a] ns, *, ** indicate no significance, and significance at the 0.05 and 0.01 probability levels, respectively.
[b] Tester = mean of all the crosses for the best tester.

were not different from zero for environments 2, 3, and 4. Environment 2 was the only environment in which the main effects for lines and testers and the line x tester interaction were not significantly greater than zero.

A range of variability among testcrosses, testers, and lines was expected because the environments ranged from 53 to 1,000 m above sea level, but the main inferences will be made from the combined analysis across the seven environments (Table 3). Differences among environments, lines, testers, and the interactions of lines and testers with environments were highly significant ($P \leq 0.01$). The mean squares for the interactions of lines and testers with the environments were small compared with the mean squares for the main effects of lines and testers. The interactions of lines and testers with environments and lines x testers, however, were highly significant in all instances. The differences among lines and testers were highly significant, indicating that there were differences among lines and testers across environments. The lines x testers interaction also was highly significant, indicating that the seven testers either ranked the lines differently or the magnitude among lines was different. Orthogonal comparisons among testers were highly significant for the comparison between tester 6 (a synthetic cultivar) vs. 7 (an inbred line) and for the comparison between testers 3 vs. 4 and 5, which were single crosses. The contrasts between the single-cross testers vs. the synthetic and the inbred testers were not significant.

The mean yield of the 147 testcrosses from the combined analysis across environments was 6.09 t/ha, which was 0.39 t/ha less than the yield of testcrosses for the greatest yielding tester (tester 5). The mean yield (7.33 t/ha) of the best three testcrosses was 1.24 t/ha greater than the mean (6.09 t/ha) of the 147 testcrosses and 0.97 t/ha greater than the yield of the best check, ICTA HB-85. Although the first-order interaction mean square for lines x tester was highly significant, the mean square of the main effect of testers was 5.8 times greater and the mean square for the main effect of lines was 2.6 times greater than the line x tester mean square. De Rissi and Hallauer (1991) also studied different types of testers and in all instances, the variance components of lines were greater than their respective line x tester interactions.

The relative rankings for yield of the 21 lines by the seven testers and the seven testers by the 21 lines were used to calculate the rank correlation among testers and among lines (Kendall and Smith, 1939). Highly significant coefficients of concordance were obtained for the ranking of the 21 lines by the seven testers (0.485) and for the ranking the seven testers by the 21 lines (0.350). The two estimates of coefficients of concordance suggest that the rankings of the lines x testers and of the testers x lines were relatively consistent.

One of the main objectives of this study was to determine the more convenient tester for ranking the set of 21 lines. An ANOVA for èach tester across the seven environments was conducted (Table 4). Most of the variation for each of the testers was due to environmental effects. For each tester, the differences among testcrosses were significant as well as the interaction of the testcrosses x environments. Single-cross tester 3 had the lowest average yield (5.69 t/ha) across the 21 lines, but it had the largest variation (0.75) among testcrosses. Tester 6 (a synthetic cultivar) had the second highest yield (6.35 t/ha) across lines, but tester 6 had the least variation (0.08) among testcrosses. The variation among testcrosses for tester 7 (0.35), which is an inbred, was not as great as was expected. Matzinger (1953) and Getschman and Hallauer (1991) reported greater variability among testcrosses using an

TABLE 4 - *Means squares, means, and C.V. for yield (t/ha) from the combined analysis of variance for each tester of corn evaluated at seven environments in Guatemala.*

Source of variation	d.f.	Testers[a] 1	2	3	4	5	6	7
Environments (E)	6	194.18**	158.26**	178.23**	217.76**	201.52**	200.99**	170.35**
Replications (R)/E	7	2.70**	1.34ns	2.24**	2.18**	1.78**	1.60*	2.27**
Lines (L)	20	4.58**	3.36**	12.72**	6.25**	4.10**	2.17*	6.21**
L x E	120	1.65**	1.04*	2.21**	1.45**	1.11**	1.12**	1.33**
Error	140	0.79	0.75	0.61	0.74	0.67	0.65	0.76
Total	293							
Yield mean		5.98	5.98	5.69	6.32	6.48	6.35	5.82
Variation (L)[b]		0.21	0.16	0.75	0.34	0.21	0.08	0.35
Variance (L x E)[c]		0.43	0.14	0.80	0.36	0.22	0.52	0.28
C.V. (%)		14.90	14.50	13.70	13.60	12.60	12.70	15.00

[a] ns, *, ** indicate no significance, and significance at the 0.05 and 0.01 probability levels, respectively.
[b] Variation for lines (L) based on the expected mean squares.
[c] Estimates of L x E interaction component of variance based on the expected mean squares.

inbred line than using either single crosses or double crosses as testers. MATZINGER (1953) reported that the variance for the lines x testers interaction decreased as the heterogeneity of the tester increased. Testcross means for testers 4, 5, and 6 were greater than the mean for the 147 testcrosses. The difference in variation among testers suggests that the testers have different genetic factors for discriminating differences among lines for their relative yields in crosses.

Only 5 of the 21 possible Pearson correlations between the seven testers were significant (correlations not shown). The correlations between each tester with the mean of the seven testers, however, were significant for all testers except for tester 3. The non-significant correlation for tester 3 is the only one that disagreed with the highly significant coefficient of concordance (W). KELLER (1949) suggested that use of two or more testers allows comparisons of the rankings by the testers as well as the variances among the testcrosses for each tester.

TABLE 5 – *Means for yield and for agronomic traits for each tester from evaluation of 147 testcrosses between 21 lines and seven testers of corn across seven environments in Guatemala.*

Tester	YIELD	STAND	SILK	PLTH	EARH	HUM	HUSK	RLODG	SLODG	PROLIF	EROT
	t/ha	no.		cm		%					
1	5.98	41.4	64.0	231.9	122.4	19.7	5.8	2.7	1.0	92.0	14.2
2	5.98	40.8	63.1	233.2	123.9	19.5	4.5	4.2	1.0	94.6	14.2
3	5.69	39.4	64.3	232.1	122.6	20.0	5.7	2.4	0.4	92.1	13.0
4	6.32	41.4	64.7	233.7	123.7	20.1	4.3	4.5	0.5	95.8	12.4
5	6.48	42.0	64.0	238.1	129.8	19.5	3.6	5.5	0.8	94.9	12.0
6	6.35	41.5	63.4	226.1	117.9	19.9	3.1	5.3	0.7	98.1	11.1
7	5.82	40.3	63.5	225.8	118.1	19.9	4.0	2.3	0.5	96.3	15.2
Average	6.09	40.9	63.9	231.6	122.6	19.8	4.4	3.8	0.7	94.8	13.2
LSD (P = 0.05)	0.79	2.8	1.3	11.2	9.8	1.1	3.9	6.3	2.7	8.9	8.3

Traits[a]

[a] Traits designations are as follows: grain yield (YIELD) in metric tons per hectare; number of plants at harvesting (STAND); number of days from planting to silk emergence (SILK); plant (PLTH) and ear (EARH) height; % of grain humidity (HUM) at harvesting; % of plants with bad husk cover (HUSK); % of plants with root (RLODG) and stem (SLODG) lodging; number of ears relative to number of plants in percentage (PROLIF); and % of ears rotted (EROT).

TABLE 6 - *Yield mean (t/ha) for each testcross between line and tester and general combining ability estimate for testers and lines based on evaluation of 147 testcrosses of corn across seven environments in Guatemala.*

	Tester								
Line	1	2	3	4	5	6	7	X[a]	GCA[b]
1	4.65	5.75	5.96	6.74	6.75	6.62	6.32	6.11	0.02
2	5.58	5.68	6.89	5.83	5.52	5.66	5.16	5.62	–0.47
3	5.74	6.14	6.37	6.56	6.09	6.43	5.80	6.16	0.07
4	6.31	6.36	3.59	6.86	7.28	6.60	5.24	6.03	–0.06
5	6.21	6.40	5.97	6.45	6.06	6.53	6.06	6.24	0.15
6	6.33	5.88	5.98	6.26	6.46	6.66	5.98	6.22	0.13
7	5.47	5.59	5.62	5.58	5.31	5.54	5.28	5.48	–0.60
8	6.14	6.11	6.13	6.44	6.16	6.22	5.92	6.16	0.07
9	5.54	5.68	5.20	5.62	6.74	5.84	5.21	5.69	–0.40
10	6.43	6.55	6.64	6.69	6.68	6.64	6.26	6.56	0.47
11	5.78	6.52	6.00	6.50	6.75	6.15	6.70	6.34	0.25
12	6.22	6.38	6.16	4.10	6.97	6.17	6.53	6.08	–0.01
13	7.10	5.93	3.65	7.11	7.38	7.20	6.94	6.47	0.38
14	6.91	6.63	6.69	7.32	7.08	6.60	6.28	6.79	0.70
15	6.02	6.46	5.93	6.78	6.92	6.72	6.23	6.44	0.35
16	6.00	5.96	6.40	6.34	6.50	6.52	5.02	6.11	0.02
17	5.58	5.71	6.09	6.01	6.02	6.00	4.49	5.70	–0.39
18	6.17	5.06	3.44	6.21	6.65	6.50	4.91	5.56	–0.52
19	6.14	6.16	6.09	6.56	5.85	6.45	6.28	6.22	0.13
20	6.25	5.92	5.47	6.40	6.41	6.40	6.28	6.16	0.07
21	4.94	4.68	6.15	6.42	6.51	5.97	5.24	5.70	–0.39
X[c]	5.98	5.98	5.69	6.32	6.48	6.35	5.82	6.09	
GCA[d]	–0.11	–0.11	–0.40	0.24	0.39	0.27	–0.27		

[a] X = mean of each line across testers, LSD (P = 0.05) = 0.77.
[b] GCA = general combining ability estimate for lines.
[c] X = mean of each tester across lines, LSD (P = 0.05) = 0.79.
[d] GCA = general combining ability estimate for testers.
LSD (P = 0.05) for the testcrosses = 0.17.

The tester means for the 11 traits across the seven environments are listed in Table 5. Least significant differences (LSD) for each trait are included to make comparisons among testers. According to the LSD value for yield (0.79 t/ha), only testers 3 and 5 had significantly different testcross means. For the other 10 traits, only plant height (PLTH) and ear height (EARH) had some instances of significant differences among means of the testcrosses.

GCA estimates for lines and testers and the mean yield for each of the 147 testcrosses across the seven environments are presented in Table 6. GCA estimates for testers ranged from –0.40 for tester 3 to 0.39 for tester 5 (Table 6). Testers 4, 5, and 6 had positive estimates of GCA, while the other testers had negative GCA estimates. The inbred tester 7 had the second smallest estimate of GCA (–0.27), while the synthetic tester 6 had the second largest GCA (0.27). For the 21 lines, the GCA estimates ranged from –0.60 for line 7 to 0.70 for line 14. Lines 14, 10, and 13 had the largest, positive GCA estimates of 0.70, 0.47, and 0.38, respectively. Line 13 x tester 5 (7.38 t/ha), line 14 x tester 4 (7.32 t/ha), and line 4 x tester 5 (7.28 t/ha) had the greatest testcross yields. The means for yield and agronomic traits expressed at each environment were significantly different (based on LSD values) among environments for all the traits except for root and stalk lodging (Table 7). These results emphasize the importance of determining the performance of different genotypes in contrasting environments, which show the level at which the genotypes selected are expected to perform.

The best 10 testcrosses for yield (t/ha) and their ranking at each environment and for the combined analysis are listed in Table 8. Nine of the best 10 testcrosses involved either line 13 or tester 5, which is a single cross. The greater ranges for the testcrosses occurred at those environments that had the greatest average testcross yields, such as environment 1 (6.89 t/ha) and environment 5 (10.00 t/ha). The ranking of the

TABLE 7 - *Means for yield and for agronomic traits for seven environments in Guatemala from the evaluation of 147 corn testcrosses between 21 lines and seven testers.*

	Traits[a]										
Environment	YIELD	STAND	SILK	PLTH	EARH	HUM	HUSK	RLODG	SLODG	PROLIF	EROT
	t/ha	------ no. ------		------ cm ------		------------------------------------ % ------------------------------------					
1	7.53	41.4	70.1	245.4	126.0	21.2	4.4	6.1	1.0	101.5	4.6
2	6.03	37.2	53.0	243.1	130.2	19.4	6.8	2.1	0.9	98.1	7.8
3	1.86	42.7	53.2	228.6	135.9	16.6	2.1	0.2	0.1	66.6	60.9
4	5.12	40.1	55.2	253.8	134.4	21.1	2.1	7.4	1.2	93.0	9.0
5	7.99	40.2	90.8	210.6	105.2	19.8	8.6	0.3	0.8	110.3	3.0
6	6.74	41.5	62.4	228.6	120.4	18.2	2.7	1.4	0.6	97.9	4.5
7	7.34	41.8	62.4	210.7	106.2	22.3	4.2	9.5	0.5	96.1	2.5
Average	6.09	40.7	63.9	231.6	122.6	19.8	4.4	3.8	0.7	94.8	13.2
LSD (P = 0.05)	1.34	4.7	3.1	22.3	18.8	1.8	6.2	10.1	2.9	12.0	11.6

[a] Traits designations are as follows: grain yield (YIELD) in metric tons per hectare; number of plants at harvesting (STAND); number of days from planting to silk emergence (SILK); plant (PLTH) and ear (EARH) height; % of grain humidity (HUM) at harvesting; % of plants with bad husk cover (HUSK); % of plants with root (RLODG) and stem (SLODG) lodging; number of ears relative to number of plants in percentage (PROLIF); and % of ears rotted (EROT).

mean value of the 147 testcrosses, however, was generally consistent across the different environments. There were testcrosses that performed better than the best check, ICTA HB-85. There were significant differences among the best 10 testcrosses for yield across the seven environments (Table 8). If the 10 best testcrosses are compared with the best check and the LSD (0.17 t/ha) used to determine significance, each of the 10 testcrosses was significantly greater yielding than the yield of the best check (6.35 t/ha). The testcross line 4 x tester 5

TABLE 8 - *Yield (t/ha) across seven Guatemala environments and ranking for the best 10 testcrosses based on the combined analysis from the evaluation of 147 testcrosses of corn between 21 lines and seven testers.*

		Environments						
Crosses[a]	Combined[b]	1	2	3	4	5	6	7
L13 x T5	7.38/1[c]	9.98/3	5.64/113	2.08/49	7.94/2	9.56/12	7.76/10	8.72/5
L14 x T4	7.32/2	8.97/22	5.94/86	2.32/34	8.18/1	9.22/17	7.64/17	8.96/1
L4 x T5	7.28/3	9.06/17	5.94/85	1.42/113	6.48/18	10.80/3	8.67/1	8.56/8
L13 x T6	7.20/4	10.14/2	5.30/131	1.74/77	7.00/6	10.08/6	7.76/11	8.42/12
L13 x T4	7.11/5	9.82/5	5.08/140	2.49/26	6.62/14	10.45/5	7.36/33	7.92/37
L13 x T1	7.10/6	9.86/4	5.82/98	1.72/81	6.81/8	9.11/22	7.52/24	8.86/3
L14 x T5	7.08/7	8.96/23	7.03/8	2.86/13	7.06/4	9.12/21	7.09/50	7.46/83
L12 x T5	6.97/8	10.20/1	6.38/40	2.32/33	6.16/25	8.84/30	7.24/40	7.63/63
L13 x T7	6.94/9	9.14/15	5.48/125	2.20/42	6.72/10	9.48/14	6.78/84	8.82/4
L15 x T5	6.92/10	8.36/37	6.32/48	3.16/4	6.80/9	8.16/79	7.80/9	7.82/47
Mean[d]	6.09/88	7.53/81	6.03/75	1.86/64	5.12/72	7.99/94	6.74/85	7.34/89
Check[e]	6.35/58	7.46/86	5.31/131	2.66/19	5.20/65	8.40/60	7.26/40	8.18/18
LSD/P = 5%	0.17	0.18	0.23	0.10	0.20	0.18	0.13	0.17
Range[d]	3.94	6.89	5.04	3.27	5.88	10.00	5.46	4.42

[a] Crosses = L identifies the number of the line, and T identifies number of the tester involved.
[b] Combined = yield mean from the combined analysis across the seven environments.
[c] Numbers after the slash indicate the ranking of that yield in the experiment.
[d] Mean and Range = from the 147 testcrosses included in the experiment.
[e] Check = the best check from the combined analysis, which was ICTA HB-85.

TABLE 9 - *Ranking from yield (t/ha) of 21 lines by seven testers and statistics parameters estimated as useful information for selecting a convenient tester for a hybrid corn breeding program in Guatemala.*

	Testers							
	1	2	3	4	5	6	7	X[a]
Rank	Lines							
1	13	14	14	14	13	13	13	14
2	14	10	10	13	4	15	11	10
3	10	11	16	4	14	6	12	13
4	6	15	3	15	12	10	1	15
5	4	5	12	1	15	1	14	11
6	20	12	21	10	1	14	19	5
7	12	4	8	19	11	4	20	6
8	5	19	19	3	9	5	10	19
9	18	3	17	11	10	16	15	20
10	19	8	11	5	18	18	5	3
11	8	16	6	8	21	19	6	8
12 (mean)	15	13	5	21	16	3	8	1
13	16	20	1	20	6	20	3	16
14	11	6	15	16	20	8	7	12
15	3	1	2	6	8	12	4	4
16	2	17	7	18	3	11	21	21
17	17	9	20	17	5	17	9	17
18	9	2	9	2	17	21	2	9
19	7	7	13	9	19	9	16	2
20	21	18	4	7	2	2	18	18
21	1	21	18	12	7	7	17	7
Per se[b]	5.86	6.90	5.94	5.35	4.50	5.72	2.51	5.25
Crosses[c]	5.98	5.98	5.69	6.32	6.48	6.35	5.82	6.09
Variance[d]	4.58	3.36	12.72	6.25	4.10	2.17	6.21	
GCA[e]	–0.11	–0.11	–0.40	0.24	0.39	0.27	–0.27	
Correlation[f]	0.61**	0.77**	0.28ns	0.55**	0.52*	0.73**	0.77**	

[a] Ranking based on the mean of the seven testers.
[b] Yield tester per se.
[c] Mean of the testcrosses.
[d] Testcross mean square.
[e] General combining ability.
[f] Correlation with mean of seven testers.

had relatively better yields in higher yield environments (1, 5, 6, 7), but relatively poorer yields in poorer yield environments (2 and 3). Different genotypes may have to be considered for different environments after considering the profitability of seed production.

A summary of the information for making the choice of the more convenient tester is included in Table 9. The ranking of the lines by the testers in descending order, based on the mean performance of the seven testers, is shown in the column identified as X. The dotted line at the center of Table 9 is the position of the testcross mean for the average of the seven testers (6.09 t/ha). Table 9 also includes the performance of each tester itself (per se), the average of the testcrosses for each tester (crosses), the variance estimate for each tester (variance), the GCA estimate for each tester (GCA), and the correlations between each tester and the overall mean of the seven testers (correlation). Some lines were ranked consistently by each of the seven testers. For instance, line 14 ranked first for the average of the seven testers, and line 14 also was among the top-ranking lines for each individual tester. Similar consistency occurred for lines 13 and 10. Similar consistency of ranking was observed for some lines that had relatively poor testcross yields for each tester; for instance, lines 7 and 2 (Table 9). There were some lines that had inconsistent testcross yields among the different testers. Line 9, for example, had a relatively low ranking of testcross yield by seven testers, but line 9 had the eighth ranked testcross yield with tester 5 (Table 9). GENTER (1963) proposed that genes from the tester parent could mask and interact with those from the inbreds in crosses; thus, the performance of the testcrosses would not accurately determine genotype of the lines under study.

Testers are used to discard lines that have below-average combining ability. Based on that concept and considering the mean of the seven testers as a reference point, tester 7, which is an inbred, is one tester that ranked the 21 lines similar to the mean of the seven testers. Eleven lines ranked above the mean by tester 7 also were above the mean based on the average of the seven testers. Tester 7 had the highest correlation with the average of the seven testers (r = 0.77). For practical reasons, however, tester 7 would not be the more suitable tester in Guatemala because tester 7 is an inbred line. Tester 7 identified superior yielding single crosses, which are not recommended for the specific market in Guatemala for which hybrids are expected to be released. Tester 3 had the greatest variation among testcrosses (0.75), had the lowest GCA estimate (–0.40), and the poorest correlation with the average of the seven testers (r = 0.28) (Table 9). HALLAUER (1975) concluded that a suitable tester should provide information on the correct ranking of the relative merit of the lines under test. Although tester 3 had the largest mean square (12.72), which is a desirable feature, if we take into account the mean value from the average of the seven testers, tester 3 would have eliminated lines 13 and 15, which were identified by other testers to be included among the best lines. Tester 6 had a broader genetic base and had a high correlation (r = 0.73) with the average of the seven testers, and tester 6 also had the lowest variation among testcrosses (0.08) (Table 4). A comparison of the relation of tester performance per se with the variation among their testcrosses did not show a definite trend. These results disagree with the results reported by RAWLINGS and THOMPSON (1962) and HALLAUER and LOPEZ-PEREZ (1979), who concluded that the assumed lower frequency of favorable alleles at important loci present in low performing testers will give the greatest variability among testcrosses, which is desirable for efficient selection among lines.

The results of this study, and those obtained by other authors, emphasized the relative nature in the choice of the best tester. The proper choice of testers has to depend on the objectives of each specific program. This was emphasized by MATZINGER (1953) and HALLAUER *et al.* (1988), who recommended that the choice of tester by breeders for either early or late generation testing should be based on the stage of development of every breeding program, genotypes to be tested, alternative testers available, and type of hybrids expected to be produced with the materials under selection.

Based on the practical objectives of this study, tester 4 seems to be a good compromise to consider as the convenient tester. Tester 4 had the second largest variation among testcrosses (0.34) and a positive estimate of GCA (0.24), which can be important for identification of elite crosses for extensive evaluation and continued inbreeding. HORNER *et al.* (1976) stated that even though a homozygous line can be considered the best tester, if the lines under selection are expected to be used for three-way or double-cross hybrids, an established single-cross tester that is considered a good seed parent would be a good choice because the genotypes from selection would be more easily used in commercial production. The positive GCA estimate for tester 4 would be useful if that tester is expected to be involved as one parent for potential hybrids to be released. Another good feature of tester 4 was a highly significant correlation (0.55) with the average of the seven testers, which agrees with the conclusion of ABEL and POLLAK (1991) in using this information for making a choice of the more efficient tester. For the ranking observed among the 21 lines based on the mean of the seven testers, tester 4 identified 10 lines of the 12 lines above the mean. With the exception of tester 7 which is an S_3 line, all the other testers could be considered as broad-genetic base testers because the level of inbreeding of the parents involved. HALLAUER and LOPEZ-PEREZ (1979) suggested that with the heterogeneity of broad-base testers, the only objective of the testcross is to obtain an initial measure of the combining ability of the lines.

CONCLUSIONS

The combined analysis for yield (t/ha) showed highly significant differences for the sources of variation for environments, lines, testers, and the interactions of lines and of testers with environments. Highly significant differences among lines and testers indicate there were differences among lines and testers across environments. The testers x lines interaction also was highly significant, indicating inconsistent ranking of the lines by the testers.

Yield mean for the 147 testcrosses across environments was 6.09 t/ha, and the greatest-yielding tester was tester 5 (6.48 t/ha). The mean yield of the best three testcrosses was 7.33 t/ha, which was 0.97 t/ha greater than the best check, ICTA HB-85. Greater mean squares for the main effects of lines and testers than for the interaction indicated that additive genetic effects were of greater importance than nonadditive effects. Testers 4, 5, and 6 had positive estimates of general combining ability (GCA), while testers 1, 2, 3, and 7 had negative GCA estimates for yield. Lines 14, 10, and 13 had the highest, positive GCA estimates of 0.70, 0.47, and 0.38 t/ha, respectively.

Highly significant coefficients of concordance (W) were obtained for yield for both line rankings and tester rankings, suggesting that, in both instances, the rankings were relatively consistent. Similar results were obtained from the Pearson correlation coefficients between each tester with the mean of the seven testers, except for tester 3, which did not have a significant correlation with the mean of the seven testers.

There were significant differences for yield among the best 10 testcrosses across the seven environments, but the best 10 testcrosses were significantly greater yielding than the best check. Because of the range of environmental conditions of the evaluation trials, differences in ranking of the 10 best-yielding testcrosses occurred among environments. Nine of the best 10 testcrosses across the seven environments involved either line 13 or tester 5, suggesting stable expression of specific combining ability for these two genotypes. Some lines were ranked consistently by each of the seven testers; whereas, other lines were ranked inconsistently. Tester 3 had the largest variation among testcrosses, which is a desirable feature for a suitable tester.

Hallauer and Miranda (1988) and Matzinger (1953) emphasized that the choice of tester will depend on the objectives and characteristics of each specific program. Based on the practical objectives of this study, tester 4 seems to be an acceptable option to consider as the convenient tester for the situation in Guatemala. Tester 4 had the second largest variation among testcrosses, positive estimate of GCA, highly significant correlation with the average of the seven testers, and acceptable performance per se. These are the main factors considered in the choice of tester 4 as the convenient tester for the specific breeding program under consideration.

There were three-way testcrosses that performed better than the best check, ICTA HB-85; therefore, these superior testcrosses can be further evaluated as potential hybrids for release. This study emphasized the relative importance of the decisions that are necessary in making the choice of the best or more convenient tester based on the evaluation of testcrosses between a specific set of lines crossed to several alternative potential testers.

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