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CIMMYT MAIZE HYBRIDS FOR LATIN AMERICA: HEAD-TO-HEAD ANALYSIS AND PROBABILITY OF OUTPERFORMING THE BEST CHECK

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ABSTRACT - The best-performing maize hybrid sent to Latin America in 1994 as part of the first CIMMYT international hybrid trials, and later used as a regular check in trials, was CML247 x CML254, a cross between two excellent CIMMYT maize lines (CMLs). Since then, many new lowland tropical maize hybrids have been developed. Additional comparisons between newly-developed CIMMYT hybrids and CML247 x CML254 could benefit national programs, seed companies, and CIMMYT work in Latin America. This study sought to identify the best new lowland tropical maize hybrids for Latin America by using head-to-head analysis and estimating their reliability, to replace CML247 x CML254 as a check in CIMMYT hybrid trials. In head-to-head comparisons, nine new hybrids showed significant yield gains over CML247 x CML254. Hybrids CL-04368 x CL-SPLW04 and CL-02181 x CML269 had the highest yields and showed a reliability of over 0.9, suggesting that both will yield more than the old check in 9 out of 10 cases. Based on yield differences between the best new hybrid and the old check, the estimated genetic gain achieved by CIMMYT's breeding efforts in lowland tropical maize was 279 kg ha^{-1} $year^{-1}$ during 1994-2002. Only two of the hybrids studied showed significant regression slopes with respect to the check hybrid, and their advantages over the check could be due mainly to genotype x environment interaction (G x E). Hybrids CL-04368 x CL-SPLW04 and CL-02181 x CML269 will be the new checks in CIMMYT field evaluations in Latin America and could be used by seed companies and public institutions in the region per se or as sources of favorable alleles.

KEY WORDS: Breeding; Corn; Gain; Tropical; White.

INTRODUCTION

During the mid-1980s, the International Maize and Wheat Improvement Center (by its Spanish acronym, CIMMYT) intensified its efforts to develop maize hybrids for the tropics in response to growing interest among national programs and private seed companies in developing countries (Vasal *et al.*, 1992). Since then, many new lowland tropical hybrids have been developed and tested in Latin America. One of the best hybrids in the early 1990s was CML247 x CML254, which outperformed many local checks across 42 locations in 1994 (Cimmyt, 1998). The same hybrid had the highest yields in trials of the "Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales" (PCCMCA) across 16 locations in 2000 (Fuentes-López and Queme, 2001). Breeders in Latin America have recognized the value of CML247 x CML254, but poor yield performance of inbred lines is the main limitation for its expanded use. Despite these problems, this hybrid is extensively used by seed industry and therefore CIMMYT has continued to use this hybrid as a regular check in white tropical maize yield trials (Cimmyt, 1998, 1999, 2000, and 2001); it has also been used extensively as a female parent in three-way cross combinations in El Salvador, Guatemala, Honduras, Nicaragua, Mexico, and Venezuela (Córdova and Trifunović, 2003).

Head-to-head analysis as a method for hybrid selection and advancement was established in the early 1980s (Bradley *et al.*, 1988). This analysis generally involves compiling information on the test cultivar and the check over all environments where both are grown (Eskridge and Mumm, 1992). The advantage of using head-to-head analysis on hybrids is that breeders can compare two or more hybrids in every experiment where they were grown together, regardless of experimental design, number of replications, and other entries evaluated in the trial. Only two hybrids are considered at a time so that the maximum number of locations can be used for comparison (Troyer and Rosenbrook, 1983). Ad-

Abbreviation: RNi, reliability.

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ditionally, pair-wise cultivar evaluation was enhanced by using probability estimation (ESKRIDGE and MUMM, 1992) that a test cultivar outperforms the check over a broad range of environments. This probability estimation (reliability) is also easily interpretable by all decision makers: breeders, farmers, donors, and other stakeholders.

Using probability tests on uniform trials from 51 locations conducted between 1988 and 1990, CÓRDOVA *et al.* (1996) identified hybrids that showed yield advantages over local checks and consistent performance across sites in Latin America. Since this study was conducted more than ten years ago, recent CIMMYT involvement in hybrid research and additional comparisons between newly developed hybrids and the best check could bring benefits to national programs and seed companies, and further CIMMYT's work in Latin America by identifying superior germplasm and testing methodology with improved cost effectiveness. As evaluation of uniform trials in large numbers of locations can be very expensive and time consuming, head-to-head analyses can be utilized to compare the best hybrids with the best check.

The objectives of this study were (1) to identify the best new lowland tropical maize hybrids for Latin American regions using head-to-head analysis and (2) estimate their reliability as replacements for check hybrid CML247 x CML254 in CIMMYT hybrid trials. (3) Demonstrate important germplasm changes occurred during the process of hybrid breeding and the useful of new hybrids to seed industry to increase maize productivity in the developing world.

MATERIAL AND METHODS

Fourteen recently developed CIMMYT lowland tropical hybrids (Table 1) were used in this study for head-to-head comparisons and reliability estimations against long-term check hybrid CML247 x CML254. Nine hybrids were included in CIMMYT International Trials in 2001 and one in 2000; two others were evaluated for the first time in 2002 making them available to national programs and seed companies in Latin America. The remaining two hybrids have not yet been included in international trials. The meaning of CML stand for CIMMYT Maize Line after release, CL mean a coded line eventually the superior CL lines will become CML at the moment of preparation of this manuscript all CL reported remain as CL. Commercial seed industry checks were included in each of 60 sites but they were different depending of the testing region therefore they were not considered in this paper on the other hand none of the seed industry checks showed superiority to CML247xCML254.

The 14 study hybrids were compared using head-to-head analyses (BRADLEY *et al.*, 1983) based on yield trials grown in Latin America from 1999-2002. Of the ten traits used in the head-to-head comparisons, the most important, grain yield, was adjusted to 150 g kg^{-1} moisture. Other data used were ear rot (visual estimate of percent rotten kernels), grain moisture (g kg^{-1}) at harvest, percent poor husk cover (percentage calculated from the number of ears with open husks, recorded before harvest), and percent root and stalk lodging (calculated from the number of plants lodged at harvest). Male and female flowering was recorded as the number of days from first irrigation after planting to when 50% of the plants shed pollen and extruded silks. Plant appearance scores (1 = good and 5 = poor) were taken after pollination, while ear appearance (1 = good and 5 = poor) was recorded at harvest.

TABLE 1 - *Pedigree, year first evaluated in international trials, and number of environments used in head-to-head comparisons between CML247 x CML254 and 14 CIMMYT lowland tropical white maize hybrids, sorted by yield differences.*

Pedigree	Year first evaluated in international trials	Number of environments
CML478 x CML254	2001	20
CL-04368 x CL-SPLW04	2002	60
CL-04365 x CML449	2002	18
CML340 x CML254	na	15
CL-02181 x CML269	2001	23
CML449 x CML447	2000	52
CL-RCW18 x CML254	na	26
CML264 x CML269	2001	41
CL-03218 x CML384	2001	17
CL-FAWW11 x CML343	2001	23
CML36 x CML384	2001	15
CL-04353 x CML254	2001	17
CML478 x CML384	2001	20
CML269 x CML384	2001	14
CML247 x CML254	1994	

The method of ESKRIDGE and MUMM (1992) was used to determine reliability of grain yield response of a given genotype with respect to CML247 x CML254. Reliability was calculated using the equation:

$$RNi = (Z > -\bar{y}_{di} / S_{di}) \quad (1)$$

where RNi is reliability, Z is the standard normal random variable, ($\bar{y}_{di}$) is the mean difference between compared entries, and (S_{di}) is the standard deviation of mean differences based on field trial information. Reliability values near 0.5 for a given cultivar are considered low, and the cultivar is regarded as risky, given that in 50% of locations it will fail to outperform the best check. Cultivars with 0.9 reliability can be expected to outperform the best check in 90% of environments and are considered very reliable. Another advantage of this estimation method is that it explicitly weights the importance of differences in performance relative to stability when comparing the test cultivar to the check (ESKRIDGE and MUMM, 1992).

RAUN *et al.* (1993) proposed a modification of the FINLEY and WILKINSON (1963) stability analysis to measure stability of new hy-

TABLE 2 - *Differences between 14 maize hybrids and CML247 x CML254 with respect to ten different traits based on head-to-head analysis of yield trials in Latin America, sorted by yield differences.*

Hybrid	Yield ($Mg\ ha^{-1}$)	Ear rot %	Male flower. days	Female flower. days	Moisture content %	Plant appearance 1-5	Ear appearance 1-5	Root lodging %	Stalk lodging %	Poor husk cover %
CL-04368 x CL-SPLW04	2.23**	2.37**	-0.8**	-1.3**	-2.79**	0.19*	0.00	4.6**	0.8	7.9**
CL-02181 x CML269	1.36**	-0.53	-1.0**	-1.2**	-1.62*	0.23	-0.05	1.8	-4.4	-3.4*
CML478 x CML384	1.10**	0.60	-0.4	-0.2	-0.63	0.20	-0.03	-1.5	2.3	0.2
CL-FAWW11 x CML343	1.07**	1.18	1.1**	0.9**	-0.64	0.10	-0.12	-1.5	-0.8	-1.9**
CML264 x CML269	1.040**	-0.09	-1.7**	-1.4**	-2.05**	0.04	0.11	2.7	-1.0	-2.1**
CML478 x CML254	0.99**	0.13	0.2	0.5	0.30	0.34*	0.01	0.5	0.5	4.6*
CL-RCW18 x CML254	0.90**	3.77**	-0.9	-0.9*	-1.76**	0.19	0.18	0.0	0.6	4.3**
CL-03218 x CML384	0.78*	1.71	-1.5**	-1.2*	-0.97	0.14	-0.10	7.2	4.5	-1.2
CML36 x CML384	0.78	3.62*	-1.1*	-0.2	-1.96**	0.42*	0.11	0.7	-1.2	-1.8*
CL-04365 x CML449	0.72	1.07	-3.0**	-2.8**	-1.60*	0.47*	0.18	1.2	4.3	-0.4
CL-04353 x CML254	0.43*	1.30	-0.2	0.3	-1.29*	0.28*	-0.06	0.0	-5.0	-1.4
CML340 x CML254	0.400	1.51	-1.1*	-1.4**	-1.07	0.15	0.37*	-6.7*	-3.6*	-0.8
CML269 x CML384	0.31	0.98	-1.8**	-1.7**	-2.01*	0.33*	0.11	0.6	-0.1	-1.9
CML449 x CML447	0.16	2.12*	-2.6**	-2.4**	-0.84	0.38**	0.23*	20.3**	1.1	-1.1

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

brids with respect to the check. This modified stability analysis was used to compare recently developed tropical hybrids to CML247 x CML254, except that yield differences were expressed in percentages. Since hybrids were compared using head-to-head methods and grown in the same experiments, locations, and years, stability analysis is completely valid for comparing two hybrids. Another advantage is that breeders do not need to grow special experiments in large numbers of locations to be able to perform stability analyses.

RESULTS AND DISCUSSION

Pedigree data, year of evaluation in international trials, and number of environments (data points) utilized for head-to-head comparisons of the 14 hybrids relative to CML247 x CML254 are shown in Table 1. The number of data points ranged from 14 to 60. The highest number of data points (60) was for the comparison between CL-04368 x CL-SPLW04 and CML247 x CML254, while the comparison between CML269 x CML384 and CML247 x CML254 was based on 14 data points.

The differences - and their significance (paired t test) - between the 14 new hybrids and the local check for ten different traits based on head-to-head comparisons are shown in Table 2. The hybrid CL-04368 x CL-SPLW04 had the highest yield advantage, with more than 2.2 $Mg\ ha^{-1}$ over the local check. It flowered earlier and had 2.79% less moisture at harvest, but had some undesirable traits (higher ear rot and percent root lodging) compared to the local check. The hybrid CL-02181 x CML269 had a yield advantage of more than 1.3 $Mg\ ha^{-1}$ over the local check, flowered earlier with less moisture at harvest, and showed better husk cover. Seven other hybrids showed significant yield differences with respect to CML247 x CML254 based on head-to-head comparisons. All hybrids examined, with the exception of CL-FAWW11 x CML343, flowered at the same time or earlier, and had the same or lower grain moisture content at harvest as the check hybrid. This is indicative of the general trend towards earliness in CIMMYT tropical maize germplasm. The yield superiority of the hybrids developed by CIMMYT maize hybrid program in the past 10 years demonstrate the progress achieved using multilocation testing and yield stability emphasizing breeding for stress environments.

The estimated reliability of the hybrids is shown in Table 3. The two hybrids (CL-04368 x CL-SPLW04 and CL-02181 x CML269) with the highest yield differences with respect to the check hybrid also showed the highest reliability values. Their reliability values were higher than 0.90, suggesting that both hybrids will have yield advantages over the check hybrid nine times out of ten. Although hybrid CML478 x CML384 had a higher yield advantage

TABLE 3 - *Average grain yield, average yield of CML247 x CML254 in head-to-head analyses, differences with respect to CML247 x CML254 (di), standard deviation across sites tested (Sdi), and reliability (RNi) for 14 maize hybrids based on head-to-head data from yield trials in Latin America.*

Pedigree	Yield (Mg ha^{-1})	CML247 x CML254 yield (Mg ha^{-1})	di	Sdi	RNi
CL-04368 x CL-SPLW04	8.810	6.578	2.232	1.477	0.935
CL-02181 x CML269	8.064	6.705	1.359	1.200	0.907
CML478 x CML384	7.860	6.762	1.098	1.150	0.830
CL-FAWW11 x CML343	7.626	6.554	1.072	0.955	0.869
CML264 x CML269	7.881	6.844	1.037	1.441	0.764
CML478 x CML254	7.755	6.762	0.993	1.246	0.787
CL-RCW18 x CML254	6.723	5.817	0.906	1.433	0.737
CL-03218 x CML384	7.154	6.370	0.784	1.374	0.716
CML36 x CML384	7.102	6.321	0.781	1.767	0.670
CL-04365 x CML449	7.790	7.066	0.724	1.697	0.665
CL-04353 x CML254	6.799	6.370	0.429	0.764	0.712
CML340 x CML254	6.648	6.248	0.399	1.677	0.594
CML269 x CML384	6.551	6.237	0.313	1.515	0.582
CML449 x CML447	7.265	7.101	0.164	1.747	0.577

(1.098 Mg ha^{-1}) than CL-FAWW11 x CML343 (1.072 Mg ha^{-1}) over the check hybrid, the reliability of the latter was 0.869 compared to 0.83 for the former. This could be explained by the greater standard deviation of the differences between CML478 x CML384 and the check hybrid, which confirms the importance of hybrid stability across different environments. Similar results were reported by ESKRIDGE and MUMM (1992) and CÓRDOVA *et al.* (1996). The other five hybrids had RNi of over 0.7 and thus could also be used by seed companies in different parts of Latin America.

The performance per se of the lines included the new superior hybrids, although not presented in this paper merit the consideration of the seed industry for use directly in hybrid combinations or in pedigree selection projects.

The stability analysis of the studied hybrids expressed by an alternative method (RAUN *et al.*, 1993) is shown in Fig. 1. In this method, the relative stability of a hybrid with respect to the check is characterized as a function of the linear regression slope, its sign and probability being different from zero (CÓRDOVA *et al.*, 1996). A stable genotype in this analysis is defined as one with a regression slope not significantly different from that of the check hybrid. Only two hybrids herein (CML264 x CML269 and CML36 x CML384) had significant regression slopes and could be considered as unstable with respect to the check; their advantages over the check were due mainly to interaction with the environment (Fig. 1). Both hybrids performed better in relation to the check hybrid when grown in more favorable environments.

The relationship between the magnitude of the yield differences between the 14 hybrids and the check hybrid and their estimated reliability is shown in Fig. 2. It is clear that with increased yield differences estimated reliability values are also higher, which confirms the high and significant correlation coefficient (r = 0.896) between yield difference and estimated reliability.

Identifying a check hybrid in a maize improvement program is essential for evaluating genetic gains over time (CÓRDOVA *et al.*, 1996). Hybrid CML247 x CML254 was developed and tested in 1994. Because of its superior performance, it was chosen as the main check hybrid in CIMMYT's white maize tropical trials. Many new hybrids have been developed and tested since then, so the estimation of achieved genetic gains and the revalidation of CML247 x CML254 as a check hybrid would be the next logical step in the lowland tropical breeding program.

The greatest yield difference (2.232 Mg ha^{-1}) was observed between CL-04368 x CL-SPLW04 and the check hybrid. Hybrid CL-04368 x CL-SPLW04 was included in international trials in 2002, while

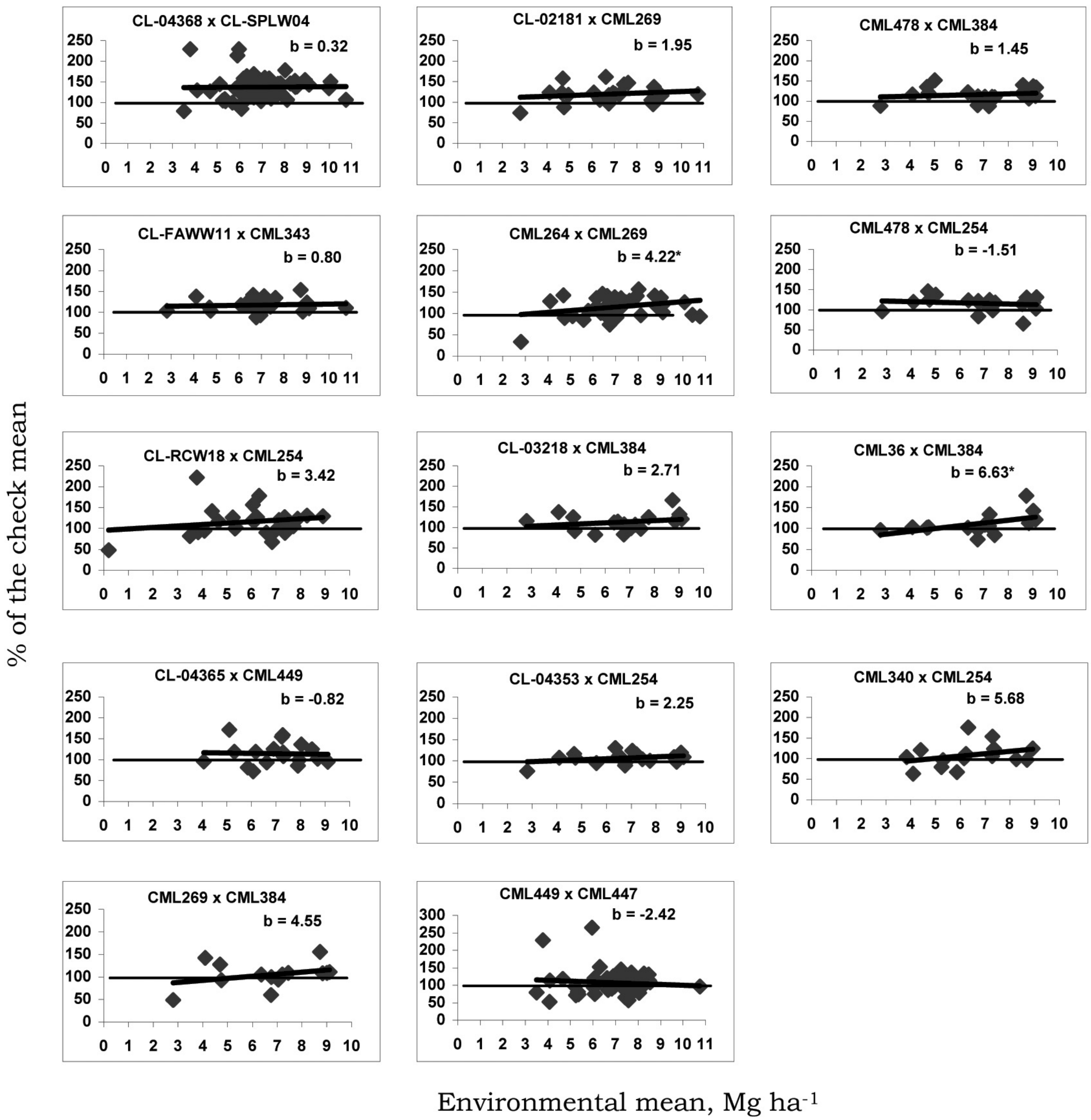

FIGURE 1 - Linear relationship of the environmental mean vs. relative yield response against CML247 x CML254 for 14 maize hybrids based on head-to-head data, in Latin America.

* Significant at the 0.10 probability level.

the check hybrid was grown for the first time in 1994. The difference of 2.232 t/ha divided by 8 years (1994-2002) shows a 279 kg ha^{-1} $year^{-1}$ genetic gain for late white materials in CIMMYT's lowland tropical subprogram. Similar calculations for temperate corn showed genetic gains in rate of 78-110 kg ha^{-1} $year^{-1}$ (Hallauer, 1973; Russell, 1974; Duvick, 1977, 1984, 1992; Eyhérabide, 1994). The much higher values of genetic gain in our study could be explained by the fact that CIMMYT's tropical hybrid breeding program is only 15 years old; therefore, all breeding methods, tools, and equipment developed in the past were already available when our hybrid research began. Also, our estimation covered an eight-year period, which is much shorter than the period used for estimating genetic gains in the studies mentioned above. The progress achieved faster is also due to genetic variability present in the tropical lowland germplasm.

In our study CL-04368 x CL-SPLW04 and CL-02181 x CML269 showed significant yield gains with very high reliability over the check hybrid; consequently, they will be the new check cultivars in CIMMYT field evaluations in Latin America. These hybrids could also be used per se or as sources of favorable alleles by seed companies and public institutions in Latin America.

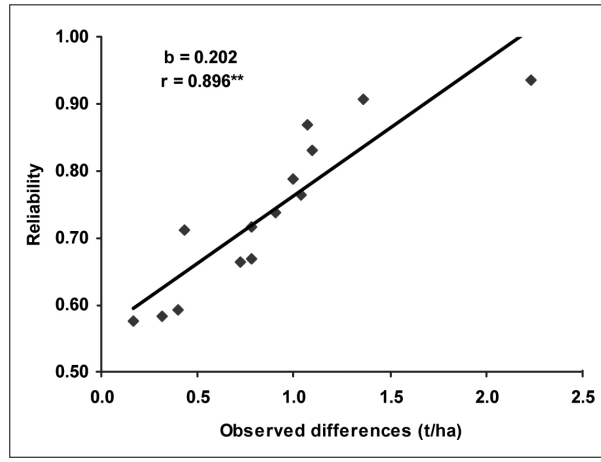

FIGURE 2 - Relationship between reliability and the magnitude of yield differences for 14 maize hybrids in Latin America.

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