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Adaptability and stability of corn hybrids grown for high grain yield

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ABSTRACT. The objective of the present study was to evaluate the adaptability and stability of corn hybrids for grain yield in environments with high crop management standards. Ten corn hybrids were evaluated for grain yield in 48 environments, consisting of 12 locations over a period of four years in South Brazil. A complete experimental, random block design with two repetitions was used. Adaptability and stability were analyzed according to the bi-segmented discontinuous model with measurement errors in the variables. The behavior of hybrids was studied as a function of the average yield in the inferior and/or superior environments, the estimates of the parameters of the equation, and the quality of the fit. The 30F36 hybrid behaved better in the superior environments and it is indicated for farmers who adopt the highest technological standards for crop management, whereas the 30F53 hybrid was classified as close to ideal; that is, it is indicated for cultivation under various environmental conditions. The 30R50 and 32R48 hybrids are appropriate only for average environments. There is a very good phenotypic stability in simple hybrids associated with high potential yield.

Keywords: *Zea mays* L., high potential, genotype vs. environment interaction, cultivar selection, bi-segmented discontinuous model.

Adaptabilidade e estabilidade de híbridos de milho em condições de alto rendimento de grãos

RESUMO. O objetivo deste trabalho foi avaliar a adaptabilidade e estabilidade do rendimento de grãos de milho em ambientes com elevados padrões de manejo da cultura. Um total de 48 ambientes, constituídos por 12 locais e quatro anos do Sul do Brasil, foi usado para a avaliação do rendimento de grãos. Foi utilizado o delineamento experimental de blocos completos ao acaso com duas repetições. A análise de adaptabilidade e estabilidade foi realizada pelo modelo bi-segmentado descontínuo, com erros de medidas nas variáveis. O comportamento dos híbridos foi estudado em função do rendimento médio nos ambientes inferiores e/ou superiores, das estimativas dos parâmetros da equação, e da qualidade do ajustamento. O híbrido 30F36 comportou-se mais adequadamente em ambientes superiores, sendo indicado para agricultores que adotam os mais elevados padrões tecnológicos de manejo, enquanto que o híbrido 30F53 foi classificado como próximo ao ideal, ou seja, indicado para cultivo em diferentes condições de ambiente. Os híbridos 30R50 e 32R48 são adequados apenas para ambientes médios. Existe estabilidade fenotípica muito boa em híbridos simples e de alto potencial produtivo.

Palavras-chave: *Zea mays* L., alto potencial, interação genótipo vs. ambiente, seleção de cultivares, modelo bi-segmentado descontínuo.

Introduction

The corn-producing regions in the southern states of Brazil experience various edaphoclimatic conditions. At these locations, corn is grown under different production systems using different degrees of technology, among other factors. The grain yield of the different genotypes within this wide production range is affected by the environment (TOLLENAAR; LEE, 2002), which may vary among locations and years, and, in this case, is more heavily influenced by the interaction between genotypes and the environment. A detailed study of genotype-environment interactions serves to characterize these crops and allows the best genotypes for the different environmental conditions to be determined. Thus, crop breeders should evaluate the magnitudes and implications of these environments to quantify their effects and provide assistance that allows for the adoption of procedures that minimize the disadvantages and/or maximize the advantages of the genotype-environment interaction (CRUZ et al., 2004). Therefore, with knowledge of the behavior of various corn genotypes under these environmental conditions, we can make inferences related to the most productive and best-adapted genotypes. In addition, it is also possible to identify a stable genotype or one that positively responds to improvements in the environmental conditions.

In breeding improvement programs, the existence of genotype-environment interactions determines the development of new genotypes, affecting the gain through selection, also hampering the recommendation of genotypes with high grain yield stability. Therefore, the adaptability and stability are analyzed to allow the identification of the genotypes with predictable behavior that may respond to the prevailing environmental variations under specific or general conditions (CRUZ et al., 2004).

In this context, adaptability refers to the ability of genotypes to successfully assimilate environmental stimuli, which is advantageous from an agricultural yield standpoint; i.e., the adaptability is evaluated based on the average performance of the genotype. Meanwhile, stability is defined as the ability of the genotypes to exhibit a yield that is as constant as possible, depending on variations in the quality of the environment (MACHADO et al., 2008). Therefore, a genotype is considered to be stable if the performance is relatively constant under various environmental conditions (ALWALA et al., 2010).

Several methods exist to analyze the adaptability and stability of genotypes when comparing their interaction with the environment. However, the bi-segmented regression model has greater flexibility to characterize the different responses of the genotypes to environmental variation than does the simple linear regression model. Thus, discontinuous bi-segmented models are appropriate, because of their simplicity of interpretation (MARODIM et al., 2000) and because they include appropriate estimations and a hypothesis test for the effect of the errors in the independent variable (STORCK; VENCOVSKY, 1994).

According to the estimations for the parameters of the discontinuous bi-segmented model, a desirable hybrid for any environment is identified by the initial half of a growth curve ($\hat{\beta}_1 < 1,\ \hat{\beta}_1 + \hat{\beta}_2 > 0$) and a good height of the curve (a high estimation for overall mean), mainly in the first half; in addition, the hybrid should exhibit an average yield greater than that of the overall average yield of the hybrids, both in the inferior and superior environments, and the estimation is therefore greater for the overall average yield. This hybrid could be recommended for any type of environment, because of its response to the environment and its potential for high productivity. The averages of the hybrids in the inferior (IE) and superior (SE) environments and the overall mean (OM), together with the estimations of other parameters, may be used to select or discard hybrids and aid crop breeders in the development and improvement of the hybrids.

Therefore, a corn genotype with high genetic potential grown under high management standard conditions (irrigation, supplementation, fertilization, and crop treatments) may exhibit different behaviors when compared over the course of different years and/or at different locations. Therefore, the adaptability and stability of corn genotypes should be studied in different environments under higher-standard management conditions to ensure the production of high yields.

In this context, the objective of the present study was to evaluate the adaptability and stability of corn hybrids for grain yield in environments managed with high crop-management standards.

Material and methods

A total of 48 environments comprising 12 locations over a period of four years (2005, 2006, 2007, and 2008) were used to evaluate the corn grain yield for ten hybrids developed for farms with high management levels (Table 1).

Table 1. State, municipality, latitude, longitude, and altitude of the areas comprising each location in which the corn trials were performed.

Location	State**	Municipality	Latitude (S)	Longitude (W)	Altitude (m)
1	PR	Abelardo Luz	$26^0$34’	$52^0$20’	800
2	PR	Cascavel	$24^0$58’	$53^0$23’	700
3	PR	Clevelândia	$26^0$24’	$52^0$22’	1,000
4	PR	Entre Rios	$25^0$35’	$51^0$40’	900
5	PR	Pinhão	$25^0$41’	$51^0$40’	1,100
6	PR	Toledo*	$24^0$40’	$53^0$46’	600
7	RS	Carazinho	$28^0$17’	$52^0$46’	550
8	RS	Cruz Alta*	$28^0$38’	$53^0$34’	450
9	RS	Passo Fundo*	$28^0$13’	$52^0$22’	700
10	RS	Sarandi*	$27^0$56’	$52^0$55’	500
11	SC	Faxinal dos Guedes	$26^0$51’	$52^0$15’	1,000
12	SC	Irani	$27^0$01’	$51^0$52’	1,000

*With supplementary center pivot irrigation **PR = state of Paraná, RS = state of Rio Grande do Sul and SC = state of Santa Catarina, Brazil.

The hybrids used to conduct the trials, which correspond to different cultivars and maturation cycles, were obtained from three private companies (Table 2). The seeding for the trials for each year was performed within the recommended period for the summer harvest in the southern states of Brazil; i.e., during the months of September and October. A randomized complete block design with two replications was used. Each plot consisted of two rows measuring 4.2 meters in length, with a spacing of 0.75 m between the rows and a density of 70,000 plants per hectare.

Management of the fertilization and crop treatments was performed based on expectations of high yield. Trials were kept free of weeds until physiological maturity, using atrazine and nicosulfuron post-emergence.

Table 2. Commercial name, type of hybrid, cycle, and seed-producing company of the ten corn hybrids tested.

Hybrid	Type of hybrid	Cycle	Company
2A120	Simple commercial hybrid	Very early	Dow AgroSciences
30F35	Simple commercial hybrid	Early	Pioneer Sementes
30F36	Simple commercial hybrid	Early	Pioneer Sementes
30F53	Simple commercial hybrid	Early	Pioneer Sementes
30K64	Simple commercial hybrid	Early	Pioneer Sementes
30P34	Triple commercial hybrid	Early	Pioneer Sementes
30R50	Simple commercial hybrid	Early	Pioneer Sementes
32R48	Simple commercial hybrid	Extremely early	Pioneer Sementes
AG8041	Simple commercial hybrid	Extremely early	Sementes Agroceres
Check*	Triple hybrid	Early	Pioneer Sementes

*Hybrid used as control for the cycle and grain quality, which is not indicated for the conditions in which the experiment was conducted.

We made four applications of insecticides (spinosad, methomyl, chlorpyrifos), to keep the trials free of pests. No fungicide application was performed. The fertilizer was applied at seeding, using 40 kg h^{-1} of N, 180 kg ha^{-1} of P_2O_5 and 130 kg ha^{-1} of K_2O. In coverage, were applied 160 kg ha^{-1} of N, in two times (5-leaf and 7-leaf stage). Of the 12 locations studied, four (Cruz Alta, Passo Fundo, and Sarandi, in Rio Grande do Sul State and Toledo in Paraná State were given supplementary irrigation using a central pivot. To determine the grain yield, two rows from each plot were collected in their entirety, which corresponded to a useful area of 6.3 m^2. The grain yield was adjusted for 13% moisture and was tested using analysis of variance (ANOVA).

The ANOVA test was performed using the model described as follows:

$$Y_{ijk} = m + c_i + \tau_j + \lambda_{ij} + b_{k(j)} + e_{ijk} \quad (1)$$

in which:

y_{ijk} is the response observed for the variable *y* in repetition *k* of hybrid *i* in environment *j*;

m is the overall expected average of the set of experiments;

c_i is the expected effect of hybrid *i*;

τ_j is the random effect of environment *j*;

λ_{ij} is the random effect of the interaction of hybrid *i* with environment *j*;

$b_{k(j)}$ is the random effect of block *k* in environment *j*;

and e_{ijk} is the random effect of the experimental error of the observation *ijk*.

Significant variation in the interaction with the environment exists, and the source of variation was explicated for 'interaction plus environment' into 'environment within the hybrids'. For the hybrids in which the variance of the environments was significant, analysis of the adaptability and stability could be performed using the bi-segmented discontinuous model with measurement errors in the variables (STORCK; VENCOVSKY, 1994); this model is characterized by the following functional and structural relationship:

$$\bar{Y}_{ij} = \beta_{0i} + \beta_{1i}\tau_j + \beta_{2i}\tau_j Z_j + \beta_{3i} Z_j + \delta_{ij} + \varepsilon_{ij} \quad (2)$$

$$\hat{\tau}_j = \tau_j + \upsilon_j \quad (3)$$

$$\hat{\tau}_j Z_j = \tau_j Z_j + \upsilon_j Z_j \quad (4)$$

$$Z_j = \begin{cases} 1, & if\ \hat{\tau}_j > 0 \\ 0, & if\ \hat{\tau}_j \le 0 \end{cases} \quad (5)$$

where:

$\bar{Y}_{ij}$ is the i^{th} hybrid in the j^{th} environment;

β_{0i} is the value of the function at point $\tau_j = 0$ of the first segment of hybrid i;

β_{1i} is the slope of the first segment of the line for hybrid *i*;

β_{2i} is the difference in the slope between the first two segments of the line for hybrid *i*, such that $\beta_{1i} + \beta_{2i}$ is the slope of the second segment of the line, which measures the discontinuity between the two segments of the line for hybrid *i*;

δ_{ij} is the deviation between the observation and the model, such that $E(\delta_{ij}^2) = \sigma_{\delta i}^2$;

ε_{ij} is the error associated with the estimator $\bar{Y}_{ij}$, which is independent of δ_{ij}, with zero expectancy and variance σ_{ε}^2;

and τ_j is the environmental index *j* (not observable) for the random effect estimated by $\hat{\tau}_j = \bar{Y}_{.j.} - \bar{Y}_{...}$ and associated with the estimation error υ_j. The parameters were estimated for each hybrid using the method of moments. The hypotheses Ho: $\beta_{1i} = 1$, Ho: $\beta_{2i} = 0$, and Ho: $\beta_{3i} = 0$ for hybrid *i* were tested using a t test. For the analysis, a computational application written in the Pascal computer language, which was specific for the model, was used (STORCK; VENCOVSKY, 1994).

The adaptability and stability of the corn hybrids was studied as a function of the average yield in the inferior and superior environments and in general, compared with the general yield of all the hybrids under these conditions as a function of the parameter estimations of the bi-segmented discontinuous equation. Finally, the stability were also studied as a function of the quality of the fit, i.e., for the greater coefficient of determination (R^2) or with less variance for the deviations of the model ($\hat{\sigma}^2_{\delta i}$).

Results and discussion

There is a very good phenotypic stability in simple hybrids and a very high grain yield potential. The environmental variances, the differences among hybrids, and the hybrid-environment interaction were all significant ($p < 0.01$); this condition is considered to be adequate for the stability analysis (Table 3). Therefore, the effect of the environment on grain yield was not the same for all hybrids. In addition, the environmental variation among the hybrids was significant ($p < 0.01$), allowing for a fit of the regression model of the yield of each hybrid in relation to the independent variable of the environmental index. The interaction between hybrid and environment was significant ($p < 0.01$). This result indicates that, even under high management conditions, the variation of the grain yield as a function of the environment is not the same for the different corn hybrids.

Table 3. Sources of variation (SV), degrees of freedom (DF), square mean (SM), coefficient of determination (R^2), and the variance of deviations ($\hat{\sigma}^2_{\delta i}$) of the bi-segmented discontinuous model for the ten corn hybrids tested in 48 environments.

SV	DF	SM	R^2(%)	$\hat{\sigma}^2_{\delta i}$
Block/Environment	48	2.684*	-	-
Environment (A)	47	77.473*	-	-
Hybrid (H)	9	84.816*	-	-
Interaction Hybrid x Environment	423	2.890*	-	-
Environment/Hybrid	470	10.348*	-	-
Env/2A120	47	8.543*	65.5	1.358*
Env /30F35	47	13.191*	81.3	1.095*
Env /30F36	47	10.789*	81.5	0.836*
Env /30F53	47	6.983*	84.3	0.371*
Env /30K64	47	10.355*	74.7	1.176*
Env /30P34	47	12.359*	72.0	1.634*
Env /30R50	47	10.080*	81.7	0.743*
Env /32R48	47	10.397*	74.4	1.190*
Env /AG8041	47	10.537*	77.4	1.054*
Env /CHECK	47	10.249*	70.8	1.364*
Error	432	0.468	-	-
Mean	-	-	76.4	1.082
CV (%)	-	5.43	-	-

* Significant ($p < 1\%$).

The estimations of the coefficient of determination and variance of the deviations have the same mean and the same degree of adaptability of the hybrids. However, the variance of the deviations may be subjected to the hypothesis test with a error-corrected due to the environmental index variable. The variance of the deviations of the bi-segmented discontinuous model ($\hat{\sigma}^2_{\delta i}$) for the environments within each hybrid lies in the range from 0.371 to 1.634 and is significant for all hybrids at 1% probability according to the t test; this result indicates unpredictable behavior in the studied environments and a low overall ability of the hybrids to adapt to new environments. To classify the hybrids into different groups, two desirable criteria would be a high coefficient of determination and a non-significant variance of the deviations (or at least a below-average mean). The hybrids 30F36, 30F53, 30R50, and AG8041 displayed less variance of the deviations according to this criterion, with values less than the mean (0.836, 0.371, 0.743, and 1.054, respectively), demonstrating good adaptability.

The average coefficient of variation (CV) was 5.43%, indicating very good experimental precision of the trials (Table 3). This mean is less than that obtained by other authors performing similar trials (MACHADO et al., 2008; COSTA et al., 2010). Analysis of the evolution of the coefficients of variation during several trials of the competition of corn hybrids has indicated that there has been a significant reduction of the experimental error in Brazilian trials in the last 15 years (FRITSCHE-NETO et al., 2012). However, the coefficient of variation is less appropriate than the coefficient of determination in evaluating experimental accuracy in trials for the competition of corn genotypes (CARGNELUTTI FILHO; STORCK, 2009), because the average yield was very different from that obtained in studies conducted under different environmental and management conditions. Therefore, because the coefficient of variation is associated with the mean and the residual variation, it is an adequate measurement of the experimental precision only when comparing trials with similar means (CARGNELUTTI FILHO; STORCK, 2007).

The average of the coefficients of determination obtained in the present study was low compared with that obtained by other authors. In the present study, the average coefficient of determination was 76.4% (range, 65.5% to 84.3%; Table 3); Marodim et al. (2000) using the same model obtained averages greater than 90%. However, by analyzing the average coefficient of determination in the present study to evaluate the experimental precision more precisely, the experimental precision may be classified as high ($R^2 = 76.4$) based on the criteria proposed by Cargnelutti Filho and Storck (2009). These authors defined high precision as prevailing when $0.6623 \leq R^2 < 0.8403$, suggesting that the hybrids that exhibit coefficients of determination greater than 66.23% should not have their degree of predictability compromised. Therefore, based on the estimations obtained for the coefficients of determination, only hybrid 2A120 failed to express a good fit with the regression model ($R^2 < 66\%$) in the studied environments, although the values were very close ($R^2 = 65.5\%$).

Among the 48 studied environments, the average grain yield was between 5.609 ton ha^{-1} in Clevelândia – Paraná State in 2005 (due to prolonged drought) and 15.238 ton ha^{-1} in Pinhão – Paraná State during the same year. As a result, these environments obtained the lowest (-6.570) and the highest (3.06) environmental indices, respectively. This result was expected, as the environmental conditions differed greatly in relation to some factors, such as precipitation (data not shown).

In the present study, the estimation of $\hat{\beta}_0$ varied between 9.452 and 13.756, with a mean of 12.179, demonstrating the high yields obtained in the trials conducted in the 48 environments over the course of four years (Table 4). The estimation of $\hat{\beta}_1$, which is used to evaluate the response of the hybrids to a variety of unfavorable environments, ranged between 0.557 (the best value, obtained for the CHECK hybrid) and 1.250 (the worst value, obtained for hybrid 30R50), and these estimations are similar to those obtained by Schmildt and Cruz (2005) and Aguiar et al. (2003) in other genotype groups. The estimations of $\hat{\beta}_2$, which evaluates the response of the hybrids to favorable environments, ranged between -0.802 (the worst value, obtained for hybrid 30R50) and 0.424 (the best value, obtained for hybrid 30F36). Meanwhile, the estimations of $\hat{\beta}_3$, which measures the discontinuity between the two line segments, ranged between -1.015 (the worst value, obtained for hybrid 2A120) and 1.452 (the best value, obtained for the CHECK hybrid). Values greater than 0 (zero) are desirable for the estimation of $\hat{\beta}_3$ because, in this case, the continuity of the line in favorable environments will start above the highest value of the line in unfavorable environments.

Table 4. Estimations of the parameters of the bi-segmented discontinuous model, the overall mean (OM), the mean in inferior environments (IE), and the mean in superior environments (SE) of ten corn hybrids (measured in ton ha^{-1}).

Hybrids	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	OM	MI	MS
2A120	12.265	0.972	0.223	-1.015	11.874	10.469	12.967
30F35	11.525	1.138	0.093	0.041	11.623	9.422	13.335
30F36	13.153	0.978	0.424	-0.350	13.298	11.345	14.818
30F53	13.131	0.894	0.096	-0.297	13.042	11.478	14.258
30K64	11.670	0.916	0.370	-0.284	11.809	9.977	13.234
30P34	12.029	1.109	-0.065	-0.046	11.951	9.979	13.484
30R50	13.476	1.250	-0.802*	0.360	13.030	11.165	14.481
32R48	13.756	1.244	-0.644	-0.028	13.220	11.456	14.592
AG8041	11.330	0.939	0.131	0.166	11.529	9.594	13.033
CHECK	9.452	0.557*	0.174	1.452	10.410	8.422	11.955
Mean	12.179	1.000	-0.000	0.000	12.179	10.331	13.616

*Hypotheses Ho: $\beta 1_i = 1$, Ho: $\beta 2_i = 0$, and Ho: $\beta 3_i = 0$, rejected by the t-test (p-value < 5%).

The average grain yield in the 48 environments was 12.179 ton ha^{-1}, which shows the high potential of the hybrids used in the trials and the high degree of crop management adopted. This average yield is far greater than those obtained in several other studies (STORCK et al., 2005; MACHADO et al., 2008; FERREIRA et al., 2010; KAPPES et al., 2011; SCHMILDT et al., 2011), above the average yield for Brazil (4.538 ton ha^{-1}), and above the average yield for southern Brazilian states (6.373 ton ha^{-1}) for the first corn harvest of 2010/11 (CONAB, 2012).

The 30F36, 30F53, 30R50, and 32R48 hybrids stood out, as they were superior to the other hybrids in their overall mean (OM), displaying a higher yield than the mean in inferior environments (IE), and greater than the mean in superior environments (SE). These same four hybrids exhibit the greatest estimations of $\hat{\beta}_0$, which determine the height of the line and consequently the potential yield of the hybrids in average environments (Table 4).

The hybrid 30F36 displays a yield that is 9.2% greater than the overall mean, 9.8% greater than the mean in inferior environments, and 8.8% greater than the mean in superior environments. According to the evaluation of the other estimations for this hybrid, this hybrid exhibited a high or above average estimation of $\hat{\beta}_0$ (13.153) and an estimation of $\hat{\beta}_1$ close to one (0.978), which varies according to the mean of the environments ($\hat{\beta}_1 < 1$). The 30F36 hybrid also exhibited a higher estimate of $\hat{\beta}_2$ (0.424), indicating that it gains more than the other hybrids when the environmental value increases above the average ($\hat{\beta}_2 > 0$). In addition, this hybrid exhibits a greater slope of the second segment of the line (segment for the favorable environments). This slope is calculated using the sum of the estimations of $\hat{\beta}_1 + \hat{\beta}_2$ (Table 4), making the value of this slope for the 30F36 hybrid equal to 1.402 (0.978 + 0.424). Moreover, this hybrid displayed a coefficient of determination greater than 80% (R^2 = 81.5%) and a variance of the deviations of the model below the mean ($\hat{\sigma}^2_{\delta i}$ = 0.836), indicating good adaptability (Table 3). Therefore, the 30F36 hybrid behaves better (displays a higher yield) in maximum or superior environments and is indicated for farmers who adopt a high technological production standard, such as appropriate correction of the soil pH, a high use of fertilizers, good control of pests and diseases, and supplementary irrigation, among other management practices.

The hybrid 30F53 displays an average yield that is 7.1% greater than the overall average, 11.1% greater than the average in inferior environments, and 4.7% greater than the average in superior environments. The high estimation of $\hat{\beta}_0$, the estimation of $\hat{\beta}_1$ of less than one (0.894), and values of $\hat{\beta}_2$ greater than zero ($\hat{\beta}_2 = 0.096$) and $\hat{\beta}_1 + \hat{\beta}_2$ almost equal to one (0.990) are all indicators that the reduction of the yield is less expressive in inferior environments and that this hybrid exhibits a better response to improved environmental and technological conditions in superior environments (Table 4). In addition, hybrid 30F53 displays a coefficient of determination greater than 80% (R^2 = 84.3%) and less variance of the deviations of the model ($\hat{\sigma}^2_{\delta i}$ = 0.371) within the group of studied hybrids, showing its good adaptability (Table 3). These factors lead to the classification of the 30F53 hybrid as close to the ideal, indicating that it is fit for cultivation in any type of environment.

The hybrid 30R50 displays the following desirable characteristics: an average yield that is 7.0% greater than the overall average, 8.1% greater than the average in inferior environments, and 6.4% greater than the average in superior environments and a high or above-average estimation of $\hat{\beta}_0$ (13.376). However, the estimation of $\hat{\beta}_1$ as greater than one (1.250) and of $\hat{\beta}_2$ as less than zero (-0.802), coupled with the low slope of the line in superior environments ($\hat{\beta}_1 + \hat{\beta}_2 = 0.457$), are indicators that in inferior environments, the slope is strong and that in superior environments, it is not very responsive to the yield in improved environmental conditions (Table 4). However, a coefficient of determination greater than 80% (R^2 = 81.7%) and a variance of the deviations of the model that is below average ($\hat{\sigma}^2_{\delta i}$ = 0.743) indicate good adaptability (Table 3). These behaviors lead to the 30R50 hybrid being recommended only for average environments. The 32R48 hybrid exhibited similar behavior to that of the 30R50 hybrid and is also indicated for medium environments, yet with less adaptability because the value of the coefficient of variation is less than 80% (R^2 = 74.4%) and the variance of the deviations of the model is above average ($\hat{\sigma}^2_{\delta i}$ = 1.190).

The results obtained with hybrids 30F36, 30F53, 30R50, and 32R48, which are classified as simple hybrids and theoretically possess a narrower genetic base, do not corroborate those of Delic et al. (2009) and Costa et al. (2010), which demonstrated that the hybrids with the greatest grain yields were usually not the most stable and that better stability was only obtained in materials with a broader genetic base, respectively. In these cases, the greater heterogeneity of the double hybrids would provide greater population buffering and greater phenotypic stability (GUILLEN-PORTAL et al., 2003). However, these results agree with those of another study that examined the adaptability and stability of different types of corn hybrids and found that the homogeneity and/or heterogeneity of hybrids do not provide more or less stability and that stable hybrids may be selected in any of the groups (MACHADO et al., 2008).

In the present study, the simple hybrid 30F53 displayed the best behavior with regard to adaptability and phenotypic stability, and it was among the three with the best overall yield, providing better estimations of the parameters of the bi-segmented discontinuous model than those exhibited by the triple hybrid 30P34, a greater coefficient of determination, and less variance in the deviations. This proved to be the most stable and adaptable hybrid, and it had a greater grain yield potential than the aforementioned triple hybrid. The results of several studies on the stability of corn hybrids indicate that differences exist among hybrids with the same level of heterozygosity and heterogeneity; however, the expression of homeostatic functions and the ability for self-regulation of the individuals (which ensures a greater degree of homeostasis) have been proven to be hybrid-specific characteristics; i.e., these abilities are inherited by the hybrids from the parents (lineages). Thus, the stability may be better in hybrids with narrower genetic bases (simple hybrids) because, due to their heterozygosity, which is displayed in the majority of the loci, they have the ability to respond to different environments more efficiently than the mixture of genotypes (BECKER; LÉON, 1988). Therefore, the characteristics of adaptability and stability are intrinsic to each hybrid, and the conclusions cannot be generalized according to the hybrid types studied (simple, triple, and double hybrids).

The results of the present study demonstrate the importance of using several parameters for adaptability and stability to determine the behavior of hybrids in different environments, even under high-yield management conditions. Inferences based on isolated estimations may lead to mistaken conclusions. Additional interpretations for the hybrids, which have not been discussed, may be made using the estimations of the parameters shown here.

Conclusion

For environments with high technological and management conditions, the best hybrid to use is 30F36. Under medium conditions, hybrids 30R50 or 32R48 may be used. The hybrid 30F53 behaves close to the ideal and may be indicated for any of the environments. There is a very good phenotypic stability in simple hybrids associated with high potential yield.

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