GMR Genetics and Molecular Research
Online Journal
ISSN:1676-5680

# Combining ability of tropical maize lines for seed quality and agronomic traits

**L.M. Moterle[1], A.L. Braccini[1], C.A. Scapim[1], R.J.B. Pinto[1], L.S.A. Gonçalves[2], A.T. do Amaral Júnior[2] and T.R.C. Silva[2]**

[1]Universidade Estadual de Maringá, Maringá, PR, Brasil
[2]Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, RJ, Brasil

Corresponding author: A.T. do Amaral Júnior
E-mail: amaraljr@uenf.br

Genet. Mol. Res. 10 (3): 2268-2278 (2011)
Received October 28, 2010
Accepted April 13, 2011
Published September 30, 2011
DOI http://dx.doi.org/10.4238/vol10-3gmr1129

**ABSTRACT.** Studies of genetic effects of early selection of maize based on seed quality traits are rare, especially those that use materials from different heterotic groups. These studies are also useful in tropical environments and for the advancement of sustainable agriculture with cropping during seasons not commonly used for cultivation. We estimated, through diallel crosses, the predominant genetic effects on the expression of agronomic traits and seed quality and on the general combining ability of nine maize lines from commercial hybrids and the specific combining ability of hybrid combinations among them. In the evaluation of seed quality, seven tests were used: first count and final count of seed germination, seedling vigor classification, cold tolerance, seedling emergence rate in a sand seedbed, speed of emergence in a sand seedbed, and speed of emergence index. Plant height, first ear height and grain yield were the estimated agronomic traits. In the diallel analysis, method 3 (model I) proposed by Griffing was used. There was a greater significance of non-additive genetic effects in the genetic control of seed quality of the various lines. The Flash, Dekalb 350 and P 30F80 lines combined high seed quality and high grain yield. For growth during the normal planting season, the combinations CD 3121-1 x P 30F80, Speed x CD 3121-2, Dow 8330 x AG 8080 and Dekalb 350 x CD 3121-2 were the most promising for both seed quality and agronomic traits.

**Key words:** *Zea mays* L.; Genetic effects; Seed quality tests; Grain yield; Early selection; Hybrids

## INTRODUCTION

The quality of seeds can be defined as the sum of all genetic, physical, physiological, and health attributes that affect their ability to perform vital functions, which is characterized by germination, vigor and longevity (Popinigis, 1985; Goggi et al., 2008). Therefore, the use of high-quality seeds is one of the essential prerequisites to achieving greater productivity in the field (Finch-Savage, 1994; Gomes et al., 2000; Munamava et al., 2004).

Despite this finding and although common maize is one of the most widely studied crops for various genetic aspects, there are few studies of genetic effects associated with seed quality (Eagles, 1982; Barla-Szabo et al., 1989; Odiemah, 1989; Hodges et al., 1997; Gomes et al., 2000; Revilla et al., 2000; Antuna et al., 2003; Hoecker et al., 2006; Cervantes-Ortiz et al., 2007).

Among the alternative methods for studying inheritance, Griffing's diallel analysis (1956) is a robust option, as it provides information on dominant gene effects for traits related to seed quality and agronomic traits.

As an example, Gomes et al. (2000) evaluated the combining ability of six tropical maize lines and found that the general combining ability (GCA) and specific combining ability (SCA), as well as the reciprocal effects, were significant ($P < 0.01$). In addition, these authors reported that the magnitude of quadratic components showed a greater significance of dominance effects for germination tests and the majority of tests used for the evaluation of seed quality, such as the germination test, germination rate index, artificial aging test, emergence in seedbed, and emergence rate index.

Hoecker et al. (2006) observed high heterosis for characteristics evaluated in the initial stages after emergence in a study that used four lines of heterotic groups of hard maize and four lines of dent maize. Similarly, Cervantes-Ortiz et al. (2007) also detected mostly dominance variance in seedling traits when studying the inheritance of seedling vigor. In contrast, Barla-Szabo et al. (1989) evaluated six temperate maize lines and demonstrated the predominance of genes with additive effects in the genetic control of seed vigor.

Therefore, there is controversy as to the inheritance of seed quality for common maize, especially for different heterotic groups and for genotypes that are adapted to tropical and temperate climates. Consequently, special attention must be paid to studies of genetic effects in common maize seeds to provide low-cost early selection, which is very important for tropical countries, so that they can use superior quality seeds. It should be pointed out that, particularly for recurrent selection programs, early selection based on physiological seed quality tests enables a time reduction in evaluating progeny, which becomes even more efficient in regions of Brazil where cultivation occurs during the normal planting season and in the second crop-growing season.

 

This is even more relevant to tropical countries and countries of continental dimensions, such as Brazil, for which maize is a staple food crop (Duarte et al., 2005; Pinto et al., 2009). In the State of Paraná, which is currently the largest producer of corn grain in the country, this significance is even more enhanced by the possibility of producing commercial crops in the normal season and in the second crop season (Aguiar et al., 2004). Therefore, it is imperative to determine the association between genetic effects of seed and plant vigor for these two cultivation periods to provide a greater supply of quality seeds to producers that are industrialized and those that have family farms.

This study aimed to estimate through diallel crossings the dominant gene effects for traits related not only to productivity but also to the quality of seeds, as well as to generate information on the combining ability of nine tropical maize lines and identify superior hybrid combinations for cultivation during the normal and second-crop seasons in the State of Paraná, Brazil.

## MATERIAL AND METHODS

### Parents and attainment of hybrids

Nine lines pre-selected for their GCA were used for grain yield in preliminary unpublished study (Table 1). The crosses were executed in a complete diallel scheme to obtain 72 $F_1$ hybrids. To obtain hybrids, seeds were cultivated with a spacing of 0.90 m between different seed lines and 0.20 m between plants in October 2007. Kraft paper bags were used to collect pollen grains during flowering to perform crosses between pairs of maize lines.

**Table 1.** Generation of self-fecundation, genealogy, origin, color, and texture of grains from the maize lines used.

| Line | Generation of self-fecundation | Genealogy | Origin | Color of grains | Texture of grains |
|---|---|---|---|---|---|
| Dow 8330 | $S_6$ | Triple hybrid | Dow AgroSciences | Orange | Flint |
| CD 3121-1 | $S_6$ | Simple hybrid | Coodetec | Yellow | Semi-dent |
| AG 8080 | $S_8$ | Triple hybrid | Agroceres | Yellow-Orange | Semi-flint |
| Flash | $S_6$ | Simple hybrid | Syngenta | Orange | Flint |
| Dekalb 350 | $S_6$ | Triple hybrid | Monsanto | Orange | Semi-flint |
| P 30F80 | $S_6$ | Simple hybrid | Pioneer | Orange | Flint |
| Strike | $S_6$ | Simple hybrid | Syngenta | Orange | Semi-flint |
| Speed | $S_6$ | Simple hybrid | Syngenta | Orange | Flint |
| CD 3121-2 | $S_6$ | Simple hybrid | Coodetec | Yellow | Semi-dent |

### Assessment of seed quality

The seed quality was evaluated using the following tests: i) first count (FC); ii) final count (GER) of seed germination; iii) seedling vigor classification (SVC); iv) modified cold (COLD); v) seedling emergence rate in sand seedbed (EME); vi) speed of emergence in sand seedbed (SE), and vii) speed of emergence index (SEI).

The tests COLD, EME and SVC were performed in accordance with the requirements contained in the Rules for Seed Analysis (Brazil, 1992). The assessments of normal seedlings were performed four and seven days after sowing. The normal plants were classified as strong normal (very vigorous) and weak normal (not very vigorous). During the first count, all normal seedlings that were well-developed and morphologically perfect were removed and classified as strong normal. The seedlings that did not meet the requirements for strong normal remained under assessment until the final count. During the final count, all remaining seedlings were assessed as normal or abnormal. The normal seedlings were classified as strong (vigorous) or weak (not vigorous) as proposed by Nakagawa (1999).

The SE trait was evaluated in conjunction with EME. The evaluation of the number of emerged seedlings, those that showed 1.00 cm growth of the canopy, was performed daily and cumulatively; therefore, the number of emerged seedlings for each count was obtained by subtracting the value obtained on the day of the reading from the value for the day before. The SEI estimates were obtained based on the proposal by Edmond and Drapala (1958).

## Assessment of agronomic traits

The tests were performed in two growing seasons, the first sown in September 2008 (normal harvest) and another in March 2009 (second crop season), using 72 simple hybrids ($F_1$s and reciprocals) and nine commercial cultivars (CD 308, XB 8030, XB 7253, XB 6012, AS 1548, XB 8010, DKB 390, AG 8088, and DKB 177). The experiments were performed using a triple-lattice design with 72 treatments, in which the experimental plot was composed of a 5.00 m long row with a spacing of 0.90 m between lines and 0.20 m between plants.

The agronomic traits evaluated were: i) plant height (PH) in cm, measured from the soil surface to the insertion of the first leaf in three competitive plants per plot; ii) height of first ear insertion (HFE) in cm, expressed as the measurement from the soil surface to the insertion of the ear in the stem in the same three plants per plot, and iii) grain yield (GY) expressed in kg/ha. The GY estimates were corrected for a standard humidity of 13%.

## Statistical analysis

The tests performed to assess seed quality were conducted using a completely randomized experimental design with four replications. The agronomic data obtained in the field, using triple lattice in two crops (2008/09 and 2009), were evaluated by joint analysis.

The results obtained for seed quality and agronomic traits were evaluated using analysis of variance with the F-test. The sum of the squares of the treatments was broken down into GCA and SCA. For the analysis, Griffing's method 3 was used for a fixed effects model (Griffing, 1956). All analyses were done using the computer application GENES program (Cruz, 2006).

# RESULTS AND DISCUSSION

## Physiological quality traits

All traits related to quality of maize seeds were significant according to the F-test (Table 2), indicating that there was sufficient genetic variability in the diallel parents and hybrids, which is extremely important for obtaining genetic gain through creating hybrids. The low variation coefficient values for the assessed traits confirm the high reliability of the results (Table 2).

By splitting the sum of squares of genotypes into sums of squares for GCA, SCA and reciprocal effect (RE), the majority of traits were significant according to the F-test, with the exception of RE and SEI, which were not significant for SCA and RE (Table 2). The signifi-

**Table 2.** Estimates of mean squares of maize genotypes (parents and $F_1$s), of general (GCA) and specific (SCA) combining abilities, of reciprocal effects (RE) and residual effects and the mean squares of combining ability effects for seven traits related to the quality of seeds evaluated in complete diallel.

| Source of variation | d.f. | Mean square of traits | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | FC | GER | SVC | COLD | EME | SE | SEI |
| Genotypes | 71 | 248.32* | 51.11* | 117.66* | 159.32* | 20.65* | $0.20^{ns}$ | 1.14** |
| GCA | 8 | 884.66* | 46.42* | 209.08* | 289.05* | 32.25* | 0.80* | 3.74* |
| SCA | 27 | 166.45* | 45.10* | 85.60* | 207.17* | 14.86* | $0.09^{ns}$ | $0.50^{ns}$ |
| RE | 36 | 168.32* | 56.67* | 121.39* | 94.61* | 22.40* | $0.16^{ns}$ | $1.04^{ns}$ |
| Error | 216 | 12.74 | 7.92 | 11.77 | 11.43 | 3.55 | 0.19 | 0.75 |
| Mean square effects | | | | | | | | |
| GCA | - | 15.57 | 0.69 | 3.52 | 4.96 | 0.51 | 0.011 | 0.05 |
| SCA | - | 19.21 | 4.65 | 9.23 | 24.47 | 1.41 | - | - |
| RE | - | 19.45 | 6.09 | 13.70 | 10.40 | 2.36 | - | - |

d.f. = degrees of freedom; FC = first count (%); GER = final count of germination (%); SVC = seedling vigor classification (%); COLD = modified cold (%); EME = seedling emergence in sand seedbed (%); SE = speed of emergence in sand seedbed (days); SEI = speed of emergence index. $^{ns}$ = not significant at 0.05 level. $^{**}$Significant at 0.01 level. $^{*}$Significant at 0.05 level.

cant mean square revealed the existence of variability resulting from additive and dominance effects in the control of gene expression. The significance of mean squares of reciprocal effects indicated the existence of significant differences with regard to the quality of seeds depending on the use of the male or female plant as the parent.

The quadratic components related to the effects of SCA were greater than those associated with GCA for the FC, GER, SVC, COLD, and EME traits, showing a greater significance of non-additive effects compared to additive effects. These results disagree with those obtained by Odiemah (1989), who found a greater significance of additive effects of genes and partial dominance of genes in the genetic control of seed quality traits in temperate maize seeds. Furthermore, Barla-Szabo (1989) and Antuna et al. (2003) demonstrated a greater influence of additive effect genes on seed vigor of maize. Nevertheless, Gomes et al. (2000) and Cervantes-Ortiz et al. (2007) showed a greater significance of dominance effect genes in the control of the quality of maize seeds.

From the estimates of quadratic components (Table 2), reciprocal effects were superior to SCA for the majority of traits, demonstrating that there is a differential effect in the use of lines as male or female parents. These results do not agree with those obtained by Gomes et al. (2000), who evaluated the combining ability of parents, $F_1$s and reciprocals of tropical maize diallels between six lines and concluded that the reciprocal effects were almost entirely inferior to the effects of SCA for genetic control of the quality of seeds. However, Gomes et al. (2000) only used lines from the flint heterotic group in the crosses, which invites related studies, especially of the greater reliability of results when they use lines of different heterotic groups in contrast to lines that only have one heterotic group. In any case, using genotypes that have fixed effects means that the results are valid for each set of materials evaluated in these studies. Nevertheless, there is no way to disprove that greater gene recombination occurs in the combination of lines of different heterotic groups, which increases the possibility that the expression of a maternal effect can serve as a reference of pertinent significance for the selection of lines as male or female parents in intercross programs to obtain superior hybrids.

According to the estimates of GCA ($\hat{g}_i$) effects, the Flash, CD 3121-1, Dow 8330, and

 

CD 3121-2 parents showed positive effects on $\hat{g}_i$ with decreasing magnitude, respectively indicating that these are genotypes that can contribute to the improvement of seed vigor (Table 3). In the GER test, Flash, Dekalb 350, P 30F80, Speed, and CD 3121-2 showed positive, decreasing values for estimates of GCA. For the SVC test, the Flash, P 30F80, Speed, CD 3121-1, Dow 8330, and CD 3121-2 lines stood out.

For the COLD test, the lines that stood out, in decreasing order, were Dekalb 350, AG 8080, P 30F80, CD 3121-1, Dow 8330, and Flash. For EME, the Dekalb 350 parent had the greatest positive effect on $\hat{g}_i$, just as in the COLD test.

**Table 3.** Estimates of the general combining ability ($\hat{g}_i$) of nine maize lines for characteristics related to the quality of seeds and agronomic traits evaluated in two growing seasons (normal crop and second crop).

| Genitors | Quality of seeds | | | | | | | Agronomic traits | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FC | GER | SVC | COLD | EME | SE | SEI | PH | | HFE | | GY | |
| | | | | | | | | 2008/09 | 2009 | 2008/09 | 2009 | 2008/09 | 2009 |
| Dow 8330 | 1.31 | -0.35 | 0.32 | 0.58 | -0.33 | 0.03 | -0.10 | -12.67 | -17.43 | -10.33 | -9.86 | -695.30 | -722.82 |
| CD 3121-1 | 2.53 | -0.10 | 0.57 | 0.69 | 0.38 | -0.03 | 0.11 | 1.88 | 5.55 | 8.18 | 4.28 | -147.89 | -439.01 |
| AG 8080 | -1.76 | -1.74 | -2.40 | 2.26 | -1.29 | 0.04 | -0.22 | 0.90 | 1.13 | -7.30 | -5.14 | 529.75 | 475.97 |
| Flash | 7.28 | 1.18 | 3.71 | 0.37 | 1.06 | -0.22 | 0.57 | 9.16 | 6.91 | 5.61 | 6.78 | 212.66 | 234.28 |
| Dekalb 350 | -7.47 | 0.83 | -2.40 | 2.58 | 1.09 | 0.22 | -0.32 | -1.08 | -4.83 | -2.82 | -2.79 | 827.35 | 460.79 |
| P 30F80 | -0.65 | 0.51 | 0.89 | 1.65 | -0.37 | -0.01 | -0.02 | 3.20 | 0.15 | 7.30 | 6.66 | 101.39 | 70.49 |
| Strike | -1.97 | -0.92 | -1.65 | -3.09 | -0.44 | 0.07 | -0.15 | -8.96 | -11.31 | -7.63 | -5.82 | -371.34 | 107.13 |
| Speed | -0.58 | 0.51 | 0.82 | -1.20 | 0.02 | -0.04 | 0.03 | 4.49 | 8.80 | -2.60 | -3.68 | 75.09 | -115.46 |
| CD 3121-2 | 1.31 | 0.08 | 0.14 | -3.84 | -0.12 | -0.06 | 0.10 | 3.08 | 11.03 | 9.60 | 9.58 | -531.71 | -71.37 |

FC = first count (%); GER = final count of germination (%); SVC = seedling vigor classification (%); COLD = modified cold (%); EME = seedling emergence in sand seedbed (%); SE = speed of emergence in sand seedbed (days); SEI = speed of emergence index; PH = plant height (cm); HFE = height of first ear insertion (cm); GY = grain yield (kg/ha).

For RE, the best lines were Flash, CD 3121-2, Speed, and CD 3121-1. In the SEI test, the lines Flash, CD 3121-1, CD 3121-2, and Speed, respectively, revealed positive and decreasing estimates of $\hat{g}_i$.

The Flash line stood out as it showed high estimates of $\hat{g}_i$ for the majority of tests, and the Dekalb 350 line stood out in the COLD and EME tests.

In regard to the effects of SCA, the hybrid CD 3121-1 x P 30F80 stood out as it had a higher GER, in addition to exhibiting favorable $\hat{s}_{ij}$ estimates in comparison to the other tests. Considering the tests in combination, the second best hybrid was Dow 8330 x CD 3121-1 (Table 4).

The effects of behavioral differentiation of hybrids when the parents were used as donors or recipients of pollen, based on the analysis of $\hat{r}_{ij}$ estimates (Table 5) for the COLD test, revealed that the hybrid CD 3121-1 x CD 3121-2 stood out based on a higher $\hat{s}_{ij}$ estimate and had better performance when the CD 3121-1 line was used for the male parent and CD 3121-2 was used for the female parent.

As in the EME test, the hybrid AG 8080 x Speed, which had the fourth highest estimate of SCA, also showed significant differences in the comparison of the $F_1$ and its reciprocal. In this case for greater seedling emergence in a sand bed, AG 8080 must be used for the male parent and the Speed line for the female parent.

It is interesting to note that for the COLD test, the hybrid that stood out exhibited a differential parental effect, although the mean square of $\hat{s}_{ij}$ was superior to that of $\hat{r}_{ij}$. Although it cannot be confirmed that the maternal effect is common for the set of parents and hybrids evaluated in regard to the COLD test, the combination CD 3121-1 x CD 3121-2, which performed better when expressing behavioral differentiation based on the genetic composition of the parents, whether masculine or feminine, reveals an interesting phenomenon for debate because both parent lines came from the same dent heterotic group. Similarly, we found a reciprocal effect in the combination AG 8080 x Speed, one of the lines that stood out for EME, and both parental lines were from the heterotic group flint. Therefore, the idea that gene reorganization for different heterotic groups is a factor that favors the expression of reciprocal effects becomes less certain, although it cannot be said that the use of parents from only one heterotic group satisfies questions about the inheritance of traits related to the seed quality. This is one justification for new investigations, especially of diallels involving materials adapted to temperate and tropical climates.

**Table 4.** Estimates of the specific combining ability ($\hat{s}_{ij}$) of nine maize lines for characteristics related to the quality of seeds and agronomic traits evaluated in two growing seasons (normal crop and second crop).

| Hybrids | Quality of seeds | | | | | | | Agronomic traits | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FC | GER | SVC | COLD | EME | SE | SEI | PH | | HFE | | GY | |
| | | | | | | | | 2008/09 | 2009 | 2008/09 | 2009 | 2008/09 | 2009 |
| 8330xCD 3121-1 | 5.40 | 4.39 | 4.39 | 4.39 | 1.10 | 5.406 | 4.39 | -5.36 | -3.39 | -2.18 | -3.89 | -57.76 | 776.65 |
| 8330xAG 8080 | -0.06 | 2.28 | 2.11 | 3.32 | 0.78 | -0.06 | 2.28 | -5.79 | 4.96 | 1.38 | 4.19 | 932.73 | 669.59 |
| 8330xFlash | -2.60 | 0.11 | -0.25 | 4.96 | 0.17 | -2.60 | 0.11 | 3.13 | -2.58 | -0.24 | 0.90 | 257.41 | -240.48 |
| 8330xDekalb 350 | -1.60 | -1.28 | -1.64 | -1.75 | 0.38 | -1.60 | -1.28 | -0.11 | 4.54 | 0.96 | 0.57 | 82.12 | -162.00 |
| 8330x30F80 | 3.33 | -1.21 | 1.07 | -0.32 | -1.15 | 3.33 | -1.21 | 4.38 | 2.46 | 9.58 | 5.38 | 89.84 | 201.53 |
| 8330xStrike | -2.10 | -2.53 | -2.64 | -9.07 | -1.33 | -2.10 | -2.53 | 8.87 | 7.01 | 1.27 | -0.38 | -775.27 | -171.89 |
| 8330xSpeed | 3.01 | 0.53 | 0.64 | -0.96 | 0.20 | 3.01 | 0.53 | -6.40 | -11.71 | -9.09 | -9.16 | -702.10 | -980.34 |
| 8330xCD 3121-2 | -5.38 | -2.28 | -3.68 | -0.57 | -0.15 | -5.38 | -2.28 | 1.29 | -1.29 | -1.68 | 2.39 | 173.03 | -93.06 |
| CD 3121-1xAG 8080 | -2.03 | 0.53 | 1.11 | -3.03 | 1.31 | -2.03 | 0.53 | 2.80 | 9.61 | -1.19 | 8.79 | 26.45 | 318.89 |
| CD 3121-1xFlash | -13.81 | -6.39 | -9.75 | -15.14 | -3.29 | -13.81 | -6.39 | 7.59 | 4.74 | 6.53 | -3.70 | 1222.66 | 282.90 |
| CD 3121-1xDekalb 350 | 1.19 | 1.21 | 2.86 | -0.61 | 0.42 | 1.19 | 1.21 | 7.72 | 2.98 | 5.06 | 2.46 | 555.50 | 236.70 |
| CD 3121-1x30F80 | 3.87 | 2.28 | 2.57 | 3.32 | 0.88 | 3.87 | 2.28 | 10.97 | 13.32 | 2.35 | 9.10 | 1133.09 | -8.99 |
| CD 3121-1xStrike | 0.19 | -2.53 | -2.89 | 1.57 | -0.29 | 0.19 | -2.53 | -0.28 | 5.36 | 0.13 | 2.68 | 32.03 | 767.57 |
| CD 3121-1xSpeed | 5.54 | 1.03 | 3.14 | 3.68 | -0.01 | 5.54 | 1.03 | -1.65 | 4.19 | -0.58 | -1.24 | 585.75 | 591.11 |
| CD 3121-1xCD 3121-2 | -0.35 | -0.53 | -1.43 | 5.82 | -0.12 | -0.35 | -0.53 | -21.80 | -36.81 | -10.12 | -14.20 | -3497.73 | -2964.83 |
| AG 8080xFlash | 3.47 | 2.25 | 2.71 | 3.03 | 1.63 | 3.47 | 2.25 | -2.14 | -4.98 | -3.40 | -3.87 | -812.22 | -261.04 |
| AG 8080xDekalb 350 | -4.53 | -2.14 | -3.68 | -4.43 | 0.35 | -4.53 | -2.14 | -1.10 | -7.56 | 0.49 | -1.14 | -1412.20 | -929.12 |
| AG 8080x30F80 | 0.40 | -1.32 | -0.21 | -3.25 | -1.69 | 0.40 | -1.32 | 0.80 | -2.42 | 1.45 | 0.18 | 147.74 | 347.94 |
| AG 8080xStrike | 3.22 | 1.86 | 2.07 | 3.75 | 0.13 | 3.22 | 1.86 | -2.68 | -6.35 | -3.24 | -5.32 | 606.44 | -27.64 |
| AG 8080xSpeed | -3.42 | -3.07 | -4.64 | 2.11 | 1.17 | -3.42 | -3.07 | -2.32 | -9.73 | 4.20 | -0.77 | 213.11 | -269.34 |
| AG 8080xCD 3121-2 | 2.94 | -0.39 | 0.53 | -1.5 | -3.69 | 2.94 | -0.39 | 10.43 | 16.47 | 0.32 | -2.06 | 297.97 | 150.71 |
| FlashxDekalb 350 | 8.19 | -0.32 | 2.71 | 1.21 | -1.01 | 8.19 | -0.32 | -3.66 | 4.79 | -5.64 | 2.34 | -421.21 | -17.24 |
| Flashx30F80 | 1.87 | 0.0 | 0.18 | -3.61 | 0.70 | 1.87 | 0.0 | -3.13 | -7.26 | 0.57 | -9.63 | 254.90 | 295.82 |
| FlashxStrike | 1.69 | 1.93 | 2.96 | 4.39 | 0.78 | 1.69 | 1.93 | -4.70 | -7.17 | -6.32 | -1.95 | 18.84 | -441.39 |
| FlashxSpeed | -0.45 | 0.25 | 0.00 | 4.75 | 0.06 | -0.45 | 0.25 | -2.25 | 3.50 | 9.12 | 5.63 | -848.25 | -418.47 |
| FlashxCD 3121-2 | 1.65 | 2.18 | 1.43 | 0.39 | 0.95 | 1.65 | 2.18 | 5.16 | 8.96 | -0.62 | 10.29 | 327.86 | 799.89 |
| Dekalb 350x30F80 | -6.13 | -0.64 | -3.46 | -0.82 | -0.33 | -6.13 | -0.64 | -2.91 | 2.57 | -3.24 | 3.12 | -80.13 | 134.59 |
| Dekalb 350xStrike | 2.94 | 1.28 | 0.82 | 0.68 | 0.24 | 2.94 | 1.28 | -3.67 | -2.95 | 2.10 | -3.79 | 329.62 | 657.18 |
| Dekalb 350xSpeed | 0.54 | 0.61 | 1.11 | 2.78 | -0.72 | 0.54 | 0.61 | 4.36 | -2.92 | -6.48 | -2.79 | 29.67 | 6.21 |
| Dekalb 350xCD 3121-2 | -0.60 | 1.28 | 1.28 | 2.93 | 0.67 | -0.60 | 1.28 | -0.64 | -1.45 | 6.75 | -0.76 | 916.64 | 73.67 |
| 30F80xStrike | -0.88 | 1.86 | 2.03 | 5.11 | 1.45 | -0.88 | 1.86 | -0.74 | 4.71 | -2.10 | -1.49 | -1019.27 | -1055.64 |
| 30F80xSpeed | -1.57 | 1.43 | -0.18 | 1.21 | -0.51 | -1.57 | 1.43 | -6.29 | -9.38 | -6.18 | -3.99 | -146.48 | -269.92 |
| 30F80xCD 3121-2 | -0.92 | -2.39 | -2.00 | -1.64 | 0.63 | -0.92 | -2.39 | -3.09 | -4.00 | -2.44 | -2.68 | -379.71 | 354.66 |
| StrikexSpeed | -5.70 | -2.39 | -3.14 | -7.28 | -1.44 | -5.70 | -2.39 | 4.55 | 3.66 | 4.70 | 7.77 | -243.01 | -33.20 |
| StrikexCD 3121-2 | 0.65 | 0.53 | 0.78 | 0.86 | 0.45 | 0.65 | 0.53 | -1.35 | -4.28 | 3.46 | 2.47 | 1050.63 | 305.01 |
| SpeedxCD 3121-2 | 2.01 | 1.61 | 3.07 | -6.28 | 1.24 | 2.01 | 1.61 | 10.00 | 22.40 | 4.31 | 4.56 | 1111.31 | 1373.94 |

FC = first count (%); GER = final count of germination (%); SVC = seedling vigor classification (%); COLD = modified cold (%); EME = seedling emergence in sand seedbed (%); SE = speed of emergence in sand seedbed (days); SEI = speed of emergence index; PH = plant height (cm); HFE = height of first ear insertion (cm); GY = grain yield (kg/ha).

**Table 5.** Estimates of reciprocal effects ($\hat{r}_{ij}$) of nine maize lines for characteristics related to plant height in two growing seasons (normal crop and second crop) and the quality of seeds.

| Hybrids | Quality of seeds | | | | | | | Agronomic traits | |
|---|---|---|---|---|---|---|---|---|---|
| | FC | GER | SVC | COLD | EME | SE | SEI | PH | |
| | | | | | | | | 2008/09 | 2009 |
| 8330xCD 3121-1 | -1.25 | 0.25 | -0.25 | 2.25 | -0.25 | -1.25 | 0.25 | 0.34 | -2.10 |
| 8330xAG 8080 | 2.50* | 2.00* | 4.00* | 2.75* | 1.75* | 2.50* | 2.00* | -1.10 | 5.69 |
| 8330xFlash | -2.00 | 1.75 | 0.25 | 1.00 | 0.00 | -2.00 | 1.75 | 1.84 | -2.13 |
| 8330xDekalb 350 | 2.25 | 0.00 | -0.75 | -5.50* | 0.25 | 2.25 | 0.00 | -3.21 | -3.59 |
| 8330x30F80 | -2.00 | 1.25 | -0.25 | 3.00* | 2.75* | -2.00 | 1.25 | -1.14 | 7.55 |
| 8330xStrike | -1.25 | 1.00 | 0.00 | -7.00* | 1.50* | -1.25 | 1.00 | -4.73 | -0.91 |
| 8330xSpeed | -0.75 | 2.00* | 1.25 | -6.00* | 1.00 | -0.75 | 2.00* | -4.89 | -3.64 |
| 8330xCD 3121-2 | 1.25 | 0.75 | 3.75* | -2.75* | -2.50* | 1.25 | 0.75 | 3.27 | 2.47 |
| CD 3121-1xAG 8080 | -0.75 | 1.50 | -0.25 | 1.50 | 1.00 | -0.75 | 1.50 | 4.28 | 5.67 |
| CD 3121-1xFlash | -2.00 | 5.00* | 2.50* | 5.50* | 1.25 | -2.00 | 5.00* | 5.17 | 9.08 |
| CD 3121-1xDekalb 350 | 7.25* | 1.25 | 2.50* | 1.75 | 0.00 | 7.25* | 1.25 | 2.68 | 2.33 |
| CD 3121-1x30F80 | -0.25 | 0.00 | -1.00 | -1.25 | -1.00 | -0.25 | 0.00 | -1.87 | -3.38 |
| CD 3121-1xStrike | -1.75 | -0.25 | -1.50 | -5.25* | -0.75 | -1.75 | -0.25 | 4.86 | -0.37 |
| CD 3121-1xSpeed | -2.00 | -0.75 | -1.50 | -2.75* | 0.00 | -2.00 | -0.75 | -0.46 | 2.48 |
| CD 3121-1xCD 3121-2 | -1.00 | -1.75 | -2.25 | -3.25* | -1.25 | -1.00 | -1.75 | -2.41 | -4.62 |
| AG 8080xFlash | -3.50* | -0.50 | -2.00 | 0.25 | 0.00 | -3.50* | -0.50 | 2.79 | 1.67 |
| AG 8080xDekalb 350 | -5.25* | -4.70* | -7.00* | -5.50* | -1.75* | -5.25* | -4.75* | -3.50 | -0.17 |
| AG 8080x30F80 | -8.00* | -4.75* | -7.75* | -5.75* | -2.75* | -8.00* | -4.75* | 0.40 | 3.00 |
| AG 8080xStrike | 2.00 | 3.50* | 3.00* | 3.00* | 2.50* | 2.00 | 3.50* | -4.74 | -1.57 |
| AG 8080xSpeed | -11.75* | -6.5* | -9.5* | -4.25* | -2.00* | -11.7* | -6.50* | 2.78 | 3.22 |
| AG 8080xCD 3121-2 | -10.00* | -5.2* | -5.5* | 0.50 | -6.50* | -10.0* | -5.25* | 4.69 | 6.76 |
| FlashxDekalb 350 | 1.00 | 0.00 | 0.50 | -1.25 | 0.75 | 1.00 | 0.00 | -4.14 | -2.78 |
| Flashx30F80 | 1.00 | 0.00 | 0.75 | -0.50 | 0.50 | 1.00 | 0.00 | 2.99 | -3.05 |
| FlashxStrike | 6.00* | 1.00 | 2.00 | -0.25 | 0.00 | 6.00* | 1.00 | -4.26 | -8.93 |
| FlashxSpeed | 2.25 | 2.25* | 3.50* | 2.00 | 0.75 | 2.25 | 2.25* | -3.50 | -5.27 |
| FlashxCD 3121-2 | 3.25* | 0.25 | 2.75* | -1.00 | 0.00 | 3.25* | 0.25 | 0.84 | -0.42 |
| Dekalb 350x30F80 | -1.25 | 3.00* | 3.50* | 2.00 | 1.50* | -1.25 | 3.00* | -3.04 | -2.36 |
| Dekalb 350xStrike | 1.50 | 2.00* | 3.25* | 2.25 | 1.00 | 1.50 | 2.00* | -12.51 | -1.77 |
| Dekalb 350xSpeed | -8.00* | -0.25 | -3.5* | 0.75 | 0.50 | -8.00* | -0.25 | -1.02 | -3.54 |
| Dekalb 350xCD 3121-2 | 3.25* | 1.50 | 5.00* | 3.25* | 0.25 | 3.25* | 1.50 | -1.87 | 0.60 |
| 30F80xStrike | -3.50* | 1.75 | 2.25 | 1.25 | -0.25 | -3.50* | 1.75 | -2.58 | -0.47 |
| 30F80xSpeed | -1.25 | 0.25 | 2.00 | 0.25 | -0.25 | -1.25 | 0.25 | -1.77 | 2.16 |
| 30F80xCD 3121-2 | 5.75* | 5.00* | 7.50* | 5.25* | 0.75 | 5.75* | 5.00* | -1.48 | -1.86 |
| StrikexSpeed | -11.25* | -5.5* | -9.5* | -5.00* | -2.25* | -11.2* | -5.50* | -3.97 | -11.86 |
| StrikexCD 3121-2 | -1.50 | 0.00 | 0.25 | 5.00* | -1.00 | -1.50 | 0.00 | -2.39 | -3.19 |
| SpeedxCD 3121-2 | -3.75* | -1.00 | 0.50 | 0.75 | -0.25 | -3.75* | -1.00 | 4.91 | 13.90 |

FC = first count (%); GER = final count of germination (%); SVC = seedling vigor classification (%); COLD = modified cold (%); EME = seedling emergence in sand seedbed (%); SE = speed of emergence in sand seedbed (days); SEI = speed of emergence index; PH = plant height (cm). **Significant at 0.01 level. *Significant at 0.05 level.

## Agronomic traits

There were significant differences, according to the F-test, for all the agronomic characteristics evaluated (Table 6), indicating the occurrence of variability between genotypes. Differentiated behavior was also seen in the set of genotypes (G) evaluated for the two growing seasons (S), based on a significance of $P < 0.01$ for G x S, which indicates that there is a possibility of recommending more promising hybrids for the normal growing season, which can be different from hybrids recommended for the second crop season.

With regard to the sources of variation for GCA and SCA, significance was found for all traits, showing that there was variability in additive genetic effects and dominance effects. However, for the source of variation in RE, only the PH trait showed significance. Therefore, there was a difference in the average height of plants depending on whether the parent was male or female.

 

**Table 6.** Estimates of mean squares of maize genotypes (parents and $F_1$s), general and specific combining abilities (GCA and SCA, respectively), reciprocal effects (RE), and residual effects for three agronomic characteristics evaluated in complete diallel in the 2008/2009 (normal crop) and 2009 (second crop) growing seasons.

| Source of variation | d.f. | Mean square of traits1/ | | |
|---|---|---|---|---|
| | | PH | HFE | GY |
| Genotypes (G) | 71 | 1046.47* | 651.18* | 5511496.60* |
| GCA | 8 | 5394.77* | 4425.46* | 14938101.41* |
| SCA | 27 | 915.72* | 293.09* | 8941539.86* |
| RE | 36 | 178.25* | 81.01$^{ns}$ | 844163.08$^{ns}$ |
| Seasons (S) | 1 | 24828.52 | 5339.63 | 1003322690.86 |
| G x S | 71 | 120.80$^{ns}$ | 68.20** | 861450.96* |
| GCA x S | 8 | 399.09* | 69.25$^{ns}$ | 1841013.29* |
| SCA x S | 27 | 131.53$^{ns}$ | 94.13* | 989415.49* |
| RE x S | 36 | 50.9$^{ns}$ | 48.52$^{ns}$ | 547797.05$^{ns}$ |
| Error | 272 | 93.06 | 45.13 | 527718.04 |

d.f. = degrees of freedom; PH = plant height (cm); HFE = height of first ear insertion (cm); GY = grain yield (kg/ha). $^{ns}$ = not significant at 0.05 level. **Significant at 0.01 level. *Significant at 0.05 level.

The mean squares for GCA x S were significant for PH and GY, while for SCA x S, there were significant differences for HFE and GY. Assuming that GY is the most important agronomic trait, the use of lines and hybrids revealed, as a whole, different behaviors for the two growing seasons evaluated. In turn, the source of variation in RE x S failed to show a significant difference for the traits evaluated, indicating that there is no variability in the hybrids depending on whether the parents are used as donors or recipients of pollen in the two growing seasons (normal crop and second crop).

The lines Dow 8330, Strike and Dekalb 350 expressed negative $\hat{g}_i$ values for PH in both crops, indicating that these genotypes contribute to a reduction in the height of plants. The parent Dow 8330 stood out with the lowest $\hat{g}_i$ effect (-12.67 and -17.43 for the normal crop and second crop growing seasons, respectively).

The analysis of average $\hat{g}_i$ effect for HFE showed a negative value. The lines Dow 8330, Strike, AG 8080, Speed, and Dekalb 350 expressed greater GCA, especially Dow 8330 with an average estimate of -10.10. The level of positive genetic contribution of these lines for a lower height of spike insertion was easily observed from their presence in the makeup of the best hybrids, based on the effect of SCA.

For GY, the parents AG 8080, Flash, Dekalb 350, P 30F80, and Speed showed positive $\hat{g}_i$ values in crops from 2008/09 (crop) and 2009 (second crop). For the 2008/09 cultivation (normal crop), the parents that expressed greater $\hat{g}_i$ estimates were Dekalb 350 (827.35) and AG 8080 (529.75); in the 2009 cultivation (second crop), the lines AG 8080 (475.97) and Dekalb 350 (460.79) stood out with higher $\hat{g}_i$ estimates.

It can be concluded that AG 8080 and Dekalb 350 are lines of interest for increasing the genetic contribution to grain yield when used in crosses to obtain superior materials for both traditional cultivation in the normal season (normal crop) and for cultivation in a not yet traditional period (second crop). This result is of great value for the exploitation of better cultivation seasons and providing increases in regional productivity without an expansion of the production area, which is in the interest of global sustainability, mainly from the better use of cultivation areas in different climatic seasons.

Comparing the yield data with the seed quality data, we conclude that the lines Flash and Dekalb 350 were the most prominent. The Flash line showed high $\hat{g}_i$ estimates for every seed quality test, while Dekalb 350 stood out in the COLD and EME tests. The greater tolerance of these lines to the COLD test showed that these are important materials for cultivation in temperate climates and are therefore of interest for future studies of climate adaptation to increase the supply of maize grains in not only tropical but also temperate environments.

The joint analysis of average estimates of SCA for the PH trait showed that the combinations Dow 8330 x Speed, Flash x Strike, AG 8080 x Strike, Dow 8330 x CD 3121-1, and AG 8080 x Dekalb 350 displayed superiority by showing more negative values for $\hat{s}_{ij}$. For HFE, the combinations Dow 8330 x Speed, Dekalb 350 x Speed, Flash x Strike, P 30F80 x Speed, and Flash x Dekalb 350 stood out with higher estimates of $\hat{s}_{ij}$ in the 2008/09 cultivation season (normal crop). For the 2009 cultivation season (second crop), the hybrids Dow 8330 x Speed, AG 8080 x Strike, P 30F80 x Speed, Dow 8330 x CD 3121-1, and AG 8080 x Flash stood out.

For GY in the 2008/09 crop, the hybrids CD 3121-1 x Flash, CD 3121-1 x P 30F80, Speed x CD 3121-2, Dow 8330 x AG 8080, Dekalb 350 x CD 3121-2, and AG 8080 x Strike produced the highest values for SCA. In the 2009 season, the highest estimates of $\hat{s}_{ij}$ were expressed by the combinations Flash x CD 3121-2, CD3121-1 x Strike, Dow 8330 x AG 8080, and Dekalb 350 x Strike. In general, the combination Dow 8330 x AG 8080 stood out in the two growing seasons. Dow 8330 x CD 3121-1 was a hybrid that stood out for PH and HFE and showed good results in the GER and seed vigor tests. CD 3121-1 x P 30F80, in addition to having a high $\hat{s}_{ij}$ value for yield, showed good performance in the majority of tests related to seed quality in the 2008/09 crop.

We found that the simple hybrids CD 3121-1 x P 30F80 and Dow 8330 x AG 8080 stood out for agronomic traits and were promising for cultivation in both growing seasons (normal crop and second crop). For cultivation in the normal planting season (normal crop), the combinations CD 3121-1 x P 30F80, Speed x CD 3121-2, Dow 8330 x AG 8080, and Dekalb 350 x CD 3121-2 were the most promising, for characteristics related to both seed quality and agronomic traits.

## ACKNOWLEDGMENTS

Research supported by the National Council of Scientific and Technological Development (CNPq) and the Araucária Foundation of Paraná State.

## REFERENCES

Aguiar CG, Scapim CA, Pinto RJB, Amaral Júnior AT, et al. (2004). Análise dialélica de linhagens de milho na safrinha. *Cienc. Rural* 34: 1731-1737.

Antuna OG, Rincón FS, Gutiérrez ER, Ruiz NAT, et al. (2003). Componentes genéticos de caracteres agronómicos y de calidad fisiológica de semillas en líneas de maíz. *Rev. Fitotec. Mex.* 26: 17.

Barla-Szabo G, Bocsi J, Dolinka B and Odiemah M (1989). Diallel analysis of seed vigour in maize. *Seed Sci. Technol.* 18: 721-729.

Brasil (1992). Ministério da Agricultura e Reforma Agrária. Regras para Análise de Sementes. SNDA/DNDV/CLAV, Brasília.

Cervantes-Ortiz F, Santos GG, Carballo-Carballo A, Bergvinson D, et al. (2007). Herencia del vigor de plántula y su relación con caracteres de planta adulta en líneas endogámicas de maíz tropical. *Agrociência* 41: 425-434.

Cruz CD (2006). Programa GENES: Análise Multivariada e Simulação. Universidade Federal de Viçosa, Viçosa.

Duarte AP, Mason SC, Jackson DS and Kiehl JC (2005). Grain quality of Brazilian maize genotypes as influenced by nitrogen level. *Crop Sci.* 45: 1958-1964.

Eagles HA (1982). Inheritance of emergence time and seedling growth at low temperatures in four lines of maize. *Theor. Appl. Genet.* 62: 81-87.

Edmond JB and Drapala WJ (1958). The effects of temperature, sand, soil, and acetone on germination of okra seeds. *Proc. Am. Soc. Hortic. Sci.* 71: 428-434.

Finch-Savage WE (1994). Influence of Seed Quality on Crop Establishment, Growth and Yield. In: Seed Quality: Basic Mechanisms and Agricultural Implications (Basra AS, ed.). Food Products Press, New York, 361-384.

Goggi AS, Caragea P, Pollak L, McAndrews G, et al. (2008). Seed quality assurance in maize breeding programs: tests to explain variations in maize inbreds and populations. *Agron. J.* 100: 337-343.

Gomes MS, Von Pinho EVR, Von Pinho RG and Vieira MGGC (2000). Estimativas da capacidade de combinação de linhagens de milho tropical para qualidade fisiológica de sementes. *Cienc. Agrotec.* 24: 41-49.

Griffing B (1956). Concept of general and specific combining ability in relation to diallel crossing system. *Aust. J. Biol. Sci.* 9: 463-493.

Hodges DM, Andrews CJ, Johnson DA and Hamilton RI (1997). Sensitivity of maize hybrids to chilling and their combining abilities at two developmental stages. *Crop Sci.* 37: 850-856.

Hoecker N, Keller B, Piepho HP and Hochholdinger F (2006). Manifestation of heterosis during early maize (*Zea mays* L.) root development. *Theor. Appl. Genet.* 112: 421-429.

Munamava MR, Goggi AS and Pollak L (2004). Seed quality of maize inbred lines with different composition and genetic backgrounds. *Crop Sci.* 44: 542-548.

Nakagawa J (1999). Testes de Vigor Baseados no Crescimento de Plantas. In: Teste de Vigor em Sementes (Vieira RD and Carvalho NM, eds.). Abrates, Londrina, 1-21.

Odiemah M (1989). Quantitative inheritance of seed quality characteristics in maize (*Zea mays* L.). *Cereal Res. Commun.* 17: 245-251.

Pinto ATB, Pereira J, Oliveira TR, Prestes RA, et al. (2009). Characterization of corn landraces planted grown in the campos gerais region (Paraná, Brazil) for industrial utilization. *Braz. Arch. Biol. Technol.* 52: 17-28.

Popinigis F (1985). Fisiologia da Semente. AGIPLAN, Brasília.

Revilla P, Malvar RA, Cartea ME, Butrón A, et al. (2000). Inheritance of cold tolerance at emergence and during early season growth in maize. *Crop Sci.* 40: 1579-1585.

 