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Adaptability and stability in commercial maize hybrids in the southeast of the State of Minas Gerais, Brazil[1]

Adaptabilidade e estabilidade de híbridos comerciais de milho no sudeste de Minas Gerais

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ABSTRACT - The aim of this study was to evaluate the adaptability and stability of 29 commercial maize hybrids in the southeast of the State of Minas Gerais, Brazil, employing three methods. The 29 commercial maize hybrids from the 2014/2015 crop were evaluated for grain yield in five locations in the southeast of Minas Gerais. A randomised-block design was used, with two replications. Each lot comprised two rows, five meters in length, at a spacing of 0.80 m, giving an effective area of 8.00 m2. In addition to individual and combined variance analysis, the methods of Eberhart & Russell (1966), AMMI (Additive Main Effects and Multiplicative Interaction Analysis) and mixed models were used to evaluate the adaptability and stability of the 29 hybrids. There was a significant difference ($P<0.01$) for the effects of hybrid, environment and the hybrid x environment interaction. The majority of the hybrids under evaluation displayed broad adaptability with good stability. It was concluded that the Eberhart & Russell, AMMI and mixed-model methods show similar results in classifying maize hybrids of broad adaptability. There is a difference in indicating hybrids with specific adaptability to favourable and unfavourable environments. Based on the three methods, the hybrids SHS7920PRO, BM709PRO2, BRS1055 and BM650PRO2 show a general adaptability for the environments under evaluation.

Key words: *Zea mays* L.. Genotype x environment interaction. Hybrid recommendation.

RESUMO - O objetivo deste trabalho foi avaliar a adaptabilidade e estabilidade de 29 híbridos comerciais de milho, no sudeste de Minas Gerais, com emprego de três metodologias. Os 29 híbridos comercias de milho foram avaliados para produtividade de grãos, em cinco locais do sudeste de Minas Gerais, na safra 2014/2015. Utilizou-se o delineamento em blocos ao acaso com duas repetições. Cada parcela foi constituída de duas linhas de cinco metros de comprimento, espaçadas em 0,80 m com área útil de 8,00 m^2. Além das análises de variâncias individual e conjunta, empregou-se os métodos de Eberhart & Russell (1966), AMMI (*Additive Main Effects and Multiplicative Interaction Analysis*) e modelos mistos para avaliar a adaptabilidade e estabilidade dos 29 híbridos. Houve diferença significativa ($P < 0,01$) para os efeitos de híbridos, ambientes e interação híbridos x ambientes. A maioria dos híbridos avaliados apresentou ampla adaptabilidade e boa estabilidade. Conclui-se que as metodologias de Eberhart & Russell, AMMI e modelos mistos, apresentam resultados semelhantes na classificação de híbridos de milho com ampla adaptabilidade; há divergência na indicação de híbridos com adaptabilidade específica a ambientes favoráveis e desfavoráveis e; com base nas três metodologias, os híbridos SHS7920PRO, BM709PRO2, BRS1055 e o BM650PRO2 apresentam adaptabilidade geral nos ambientes avaliados.

Palavras-chave: *Zea mays* L.. Interação genótipos x ambientes. Recomendação de híbridos.

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INTRODUCTION

Maize (*Zea mays* L.) is grown almost all over Brazil, in a wide variety of environments, using different production systems and levels of technology (MALDANER *et al*., 2014). The identification of genotypes with high production potential and with broad adaptability and stability is one of the principle target of maize breeding programs. This is why, before being released and recommended to farmers, hybrids are evaluated in many locations. However, cultivars evaluated in different environments may display different behaviour due to environmental variations, which would characterise the interaction between genotype and environment (HALDANE, 1946). Studying adaptability and stability is an alternative for reducing the effects of this interaction, and makes it possible to identify cultivars which have predictable behaviour, and which are responsive to environmental improvements (CRUZ; CARNEIRO; REGAZZI, 2014).

Different methods have been proposed to study the adaptability and stability of maize cultivars. Among these is the method proposed by Eberhart and Russell (1966), based on linear regression analysis, which among its advantages includes ease of application and interpretation of results. The recommendation of maize cultivars based on this method has been successfully employed by several authors (CARGNELUTTI FILHO *et al*, 2009; MIRANDA *et al*, 2009; OLIVEIRA; MOREIRA; FERREIRA, 2013; RIOS *et al*., 2009; SCAPIM *et al*., 2010), and recently, Carvalho *et al*. (2014) used this method to study the adaptability and stability of 16 maize genotypes in the state of Tocantins, and classify them as to production objective: either grain or green weight.

Among recent methods is AMMI analysis (Additive Main Effects and Multiplicative Interaction) (GAUCH; ZOBEL, 1996). It allows a more detailed evaluation of the genotype x environment interaction, and enables easy graphical interpretation of the results. The application of this analysis to evaluating maize cultivars can be found in the work of Balestre *et al*. (2009), Cargnelutti Filho *et al*. (2009) and Miranda *et al*. (2009). According to these last authors, the AMMI method is relatively simple, making it possible to study the phenotypic stability and genotypic behaviour of cultivars, as well as inferring the degree of divergence between the cultivars under evaluation.

In addition to these two methods, the method of mixed models has been used in recommending cultivars of various crops: carrots (SILVA *et al*., 2011), coffee (ROCHA *et al*., 2015) and beans (TORRES *et al*., 2015), as it displays some advantages over traditional methods (RESENDE, 2007). The method considers the errors correlated within locations, provides genetic values already discounting instability, and allows selection by three attributes at one time (productivity, stability and adaptability). Mendes *et al*. (2012) employed this method to evaluate 45 varieties of maize in 49 environments. The authors concluded that, due to the characteristics of the method, it was suitable for use in maize breeding programs.

Traditional methods for the study of adaptability and stability have been used with success in the recommendation of maize cultivars. However, work employing more modern methods, such as AMMI and mixed models, in the evaluation of maize hybrids are scarce, and need further study. Thus, the objective of this study is to evaluate the adaptability and stability of 29 commercial maize hybrids in the southeast of the State of Minas Gerais (MG), employing the methods of Eberhart and Russell (1966), AMMI and mixed models.

MATERIAL AND METHODS

For this study, twenty-nine commercial maize hybrids released by different seed companies were evaluated in five environments in the southeast of Minas Gerais in the 2014/2015 season (Table 1): The Experimental Station of Coimbra, in the town of Coimbra, MG (20º49’46.5” S, 42º45’51.1” W, altitude 715 m); The Diogo Alves de Mello Experimental Station, in Viçosa, MG (20º46’04” S, 42º52’10” W, altitude 662 m) (Viçosa1); The Horta Nova Experimental Station (20º45’47.6” S, 42º49’25.1” W, altitude 665 m), located in the district of São José do Triunfo, Viçosa, MG (Viçosa2); The Experimental Station of *Embrapa Milho e Sorgo*, in Sete Lagoas, MG (19º27’57” S, 44º14’48” W, altitude 761 m), and in São Miguel do Anta, MG (20º42’22.6” S, 42º43’09.4” W, altitude 661 m).

The experimental design was of randomised blocks with two replications. Each plot consisted of two rows, five meters in length, spaced 0.80 m apart, with an effective area of 8.00 m^2. When more than 50% of the plots had reached the V4 stage (four fully developed leaves), thinning was carried out in order to obtain a final population of 62,500 plants ha^{-1}.

In São Miguel do Anta and the Diogo Alves de Mello Experimental Station (Viçosa), planting was carried out in December 2014 under a conventional system with the area prepared by ploughing and harrowing. In the remaining areas, planting was in December of the same year under a no-till system with prior desiccation of the vegetation using glyphosate. In all locations, sowing was

Table 1 - Agronomic characteristics of 29 commercial maize hybrids evaluated for five environments in the southeast of Minas Gerais in the 2014/2015 season

Hybrids	Type	Cycle	Company	Area of Adaptation
DKB330PRO	SC	EE	Dekalb	S, CW, SE, NE and RO
BM915PRO	SC	EE	Biomatrix	SE, CW, N, S and PR
AG7098PRO2	SC	E	Agroceres	CW, SE, NE and PR, RO, TO
DKB390	SC	E	Dekalb	S, CW, SE, NE, RO, AC
P3862H	SC	E	Du Pont do Brasil	S, SE, CW and BA, TO, PI, MA
30F35	SC	E	Du Pont do Brasil	S, SE, CW, NE and TO, RO, RR, AC
2B587PW	SC	E	Dow Agrosciences	Brazil
2B710PW	SC	E	Dow Agrosciences	Brazil
30A16PW	SC	E	Morgan Sementes	Subtropical and high tropical regions
BRS1010	SC	E	Embrapa	Brazil excl. RS and SC
SHS7920PRO2	SC	E	Santa Helena	SE, CW, PR, RS
BM3066PRO2	SC	E	Biomatrix	S, SE
BM820	SC	E	Biomatrix	SE and CW
BM840PRO	SC	E	Biomatrix	SE and CW
RB9004PRO	SC	E	Riber KWS	SE, S, NE, CW, N
BM650PRO2	SC	SME	Biomatrix	SE, CW
BM709PRO2	SC	SME	Biomatrix	S, SE, CW
BRS1055	SC	SME	Embrapa	NE, SE, CW, N, PR
2B810PW	SC	N	Dow Agrosciences	Tropical and other regions
BRS3035	TC	EE	Embrapa	CW, NE, SE and PR
20A55PW	TC	E	Morgan Sementes	Brazil
BM3063	TC	E	Biomatrix	S, SE, CW, NE, N
BG7049H	TC	E	Du Pont do Brasil	S, SE, CW and BA, TO, PI, MA
2B512PW	TC	E	Dow Agrosciences	Brazil
BRS3060	TC	SME	Embrapa	SE, CW and MA, TO
BM207	DC	E	Biomatrix	S, SE, CW, NE, N
CARGO	DC	E	Syngenta	S, CW, SE
FEROZViptera	DC	E	Syngenta	S, CW, SE and BA, MA, PI
AS1573PRO	MSC	E	Agroeste	S and SP, MG, MS

Type: SC - Single cross; TC - Triple-way cross; DC - Double cross; MSC - Modified Single cross. Cycle: EE - Extra-Early; E - Early; SME - Semi-Early; N - Normal. Area: S - South; CW - Central West; SE - Southeast; NE- Northeast; N - North; PR - Paraná; RO - Rondônia; TO - Tocantins; AC - Acre; BA - Bahia; PI - Piauí; MA - Maranhão; RR - Roraima; RS - Rio Grande do Sul; SC - Santa Catarina; SP- São Paulo; MG - Minas Gerais; MS - Mato Grosso do Sul

done manually. Management and treatment were carried out in accordance with the technical recommendations for maize crops (CRUZ *et al*., 2008). When planting, 400 kg ha^{-1} of 08-28-16 formulation NPK fertiliser was applied. Later, at the V6 stage (six fully developed leaves) a topdressing of 150 kg N ha^{-1} was applied in the form of urea. Grain yield was evaluated, weighing the grain from each lot corrected for 14.5% moisture, with the values converted to kg ha^{-1}.

After collecting the data, analysis of variance was performed for each environment to analyse the existence of genotypic variability among the maize hybrids, and a combined analysis of variance, with the aim of detecting the genotype x environment interaction. Before performing the combined analysis of variance, the homogeneity of the residual variances was tested to carry out environmental clustering. (PIMENTEL-GOMES, 2000). Later, an analysis of adaptability and stability was performed using the Eberhart and Russell (1966), AMMI and mixed-model REM/BLUP methods. In the evaluation of individual genotypes, the Eberhart and Russell method (1966) uses the average productivity (β_{oi}), the regression coefficient (β_{1i}) of each genotype in relation to the environmental index, and the variation in deviation of this regression (σ^2_{di}). In using this method, the following regression model (Equation 1) was employed:

$$y_{ij} = \beta_{oi} + \beta_{1i} I_j + \delta_{ij} + \varepsilon_{ij} \qquad (1)$$

where: y_{ij} is the mean value of genotype *i*, in environment *j*; β_{oi} is the constant of the regression and represents the overall mean value for genotype *i*; β_{1i} is the linear regression coefficient which measures the response of the *i*-th genotype to variation in the environment; I_j is the encoded environmental index; δ_{ij} is the deviation of regression; and ε_{ij} is the mean experimental error.

For the AMMI analysis (GAUCH; ZOBEL, 1997), which combines into a single model additive components for the main effects of the genotypes and environments, and multiplicative components for the interaction effects, the following model was used:

$$y_{ij} = \mu + g_i + a_j + \sum\nolimits^{n}_{k=1} \lambda_k \gamma_{ik} \alpha_{jk} + \rho_{jk} + \varepsilon_{ij} \qquad (2)$$

where: y_{ij} is the average productivity of genotype *i* (i = 1,2, ..., 29) in environment *j* (j = 1,2, ..., 5); μ is the overall mean value of the experiments; g_i is the fixed effect of genotype *i*; a_j is the effect of environment *j*; λ_k is the *k*-th single value of the interaction matrix; γ_{ik} is the element corresponding to the *i*-th genotype in the *k*-th single vector column of matrix GA; α_{jk} is the element corresponding to the *j*-th environment, in the *k*-th single vector line of matrix GA; ρ_{jk} is the residual associated with the term for the classic interaction of genotype *i* with environment *j*; ε_{ij} is the mean experimental error associated with the observation, assuming $\varepsilon \sim N(0,\sigma^2)$ as independent; and *n* is the number of axes or retained main components for describing the pattern of the genotype x environment interaction.

For the mixed-model method, model 54 of the SELEGEN REML/BLUP software was used (RESENDE, 2007):

$$y = Xr + Zg + Wi + e, \qquad (3)$$

where: *y* is the data vector; *r* is the vector of fixed repetition effects added to the overall mean value; *g* is the vector of random genotypic effects; *i* is the vector of the random effects from the genotype x environment interaction; *e* is the random error vector; and X, Z and W are the incidence matrices for *b*, *g* and *c* respectively.

The joint selection, taking productivity, stability and adaptability of the maize genotypes together, was obtained from the harmonic mean of the relative performance of the predicted genotypic values:

$$MHPRVG_i = n \Big/ \sum\nolimits^{j}_{i=1} \frac{1}{PRVG_{ij}} \qquad (4)$$

where: *n* is the number of environments; $PRVG_{ij} = VG_{ij}/VG_j$, where: VG_{ij} is the genetic value of genotype *i* in environment *j*; and VG_j corresponds to the genotypic mean in environment *j*.

To facilitate interpretation of the results, the MHPRVG values were multiplied by the overall mean value, giving results of the same magnitude as the characteristic being studied. Later, the environments were grouped into favourable and unfavourable, according to the overall mean of the hybrids in all of the environments, and separate analyses were carried out for each environment group. Environments where the average value was higher than the overall average were considered favourable, and those where the average value was less than the overall average were considered unfavourable. This resulted in the creation of new values for MHPRVG for each environment group, which were compared using dispersion diagrams.

The genetic and statistical analyses were carried out with the help of the Genes (CRUZ, 2013), the SELEGEN (RESENDE, 2007) and the R Statistical Software (R Development Core Team, 2010).

RESULTS AND DISCUSSION

With the results of the individual analysis of variance, a significant difference ($P<0.05$) was found between the hybrid averages for grain yield at all the sites under evaluation (data not shown). Accuracy values ranged from 0.75 to 0.89, indicating the high precision of the experiments (RESENDE; DUARTE, 2007). Furthermore, it was found that the ratio between the largest and smallest residual mean square was less than 7.0 (2.8), which indicates homogeneity of the residual variances. This made it possible to carry out combined analysis (Table 2), which showed a significant effect ($P<0.01$) for all the tested sources of variation. The significant hybrid x environment interaction demonstrates that the hybrids had different responses in relation to the environmental changes. In the work of Balestre *et al.* (2009) and Miranda *et al.* (2009), different responses were also seen for grain yield in commercial maize hybrids when grown in different environments.

The average grain yield of the hybrids in the environments ranged from 3,163 kg ha^{-1} in São Miguel do Anta to 12,399 kg ha^{-1} in Sete Lagoas, with an overall

Table 2 - Summary of the combined analysis of variance for grain yield evaluated in 29 commercial maize hybrids for five environments in Minas Gerais, in the 2014/2015 season

SV	DOF	Mean Square	F
Block/Environment	5	3099720.87	
Hybrids	28	13735535.84	3.34**
Environments	4	773004952.01	249.38**
Hybrids x Environments	112	4114515.85	2.34**
Error	140	1756850.52	
Mean		9146.26	
CV (%)		14.49	
Accuracy		0.76	

**: significant at 1% probability by F-test

average of 9,146 kg ha^{-1}. This average was higher than the national average of 5,411 kg ha^{-1}, obtained in the last harvest (CONAB, 2016). The coefficient of variation (CV), which measures experimental accuracy, was 14.49%, classified as average for the productivity of maize grain (FRITSCHE-NETO *et al*., 2012) and indicating good experimental precision. In similar studies with maize, the value for the coefficient of variation ranged from 10.66% (CARGNELUTTI FILHO *et al*., 2009) to 22.0% (CARDOSO *et al*., 2012) for the characteristic of grain yield. Such satisfactory precision was confirmed by the high value for accuracy (0.76) obtained with the combined analysis (RESENDE; DUARTE, 2007).

According to the Eberhart and Russell method (1966), two environments were classified as unfavourable - Coimbra and São Miguel do Anta. These environments showed negative values for I_j, which are usually associated with areas of adverse weather or soil conditions, or areas with low levels of technology and little input. The environments at Viçosa1, Viçosa2 and Sete Lagoas were classified as favourable, and were where the hybrids had the highest grain yields.

When analysing the parameters of adaptability and stability by the Eberhart and Russell method (1966) (Table 3), it can be seen that 89.66% of the hybrids had regression coefficients statistically equal to one (β1i = 1) and were classified as having general adaptability. The P3862H and AG7098PRO2 hybrids were classified as having specific adaptability to favourable environments ($\beta_{1i}>1$), i.e. according to this method, these hybrids responded favourably to improvements in the environment. The CARGO hybrid had a value for β_{1i} statistically less than one ($\beta_{1i}<1$), which demonstrates the adaptability of this hybrid to unfavourable environments; it displayed no increase in grain yield with improvements in the environment, and should be recommended for areas of low investment and low levels of technology.

For phenotypic stability, 59% of the hybrids showed a deviation of regression equal to zero ($\sigma^2_{di} = 0$), which indicates the high behavioural predictability of these hybrids. In contrast, the hybrids RB9004PRO, 30A16PW, BM3063, BM3066PRO2, DKB390, 2B810PW, BM840PRO, 30F35, 20A55PW, AS1573PRO, BM915PRO and DKB330PRO showed significant deviation of regression ($\sigma^2_{di} \neq 0$), demonstrating their unpredictable behaviour in the environments. These are single hybrids, with the exception of BM3063 (TC) and 20A55PW (TC), and have a constitution of low genetic stability, as they result from the crossing of only two lines (HALLAUER; MIRANDA FILHO; CARENA, 2010). However, such results should not limit the use of these hybrids because, with the exception of hybrids RB9004PRO, 30F35, 20A55PW, AS1573PRO, BM915PRO and DKB330PRO, they had values for the coefficient of determination (R^2) of over 85%, which is recommended for maize (OLIVEIRA; MOREIRA; FERREIRA, 2013). This coefficient is an auxiliary measure of comparison between genotypes, and reflects the goodness of fit of the model to the yields observed in each of the hybrids under evaluation. These results showed that a large part of the variations was explained by the adopted model.

In the simultaneous analysis of the parameters of adaptability and stability (β_{1i} and σ^2_{di}), obtained with the Eberhart and Russell method (1966), it is found that most hybrids showed high behavioural predictability and broad adaptability. The hybrids SHS7920PRO, 30A16PW, BM709PRO2, BRS1055, FEROZViptera, BM650PRO2, BM3063, BG7049Hx, BM3066PRO2, DKB390, 2B587PW, 2B512PW and 2B810PW are noteworthy, as together with these parameters they had grain yields higher than the overall average (9,146 kg ha^{-1}). Furthermore, they had values for the coefficient of determination (R^2) greater than 85%.

Table 3 - Estimates of the parameters of adaptability and stability according to the Eberhart and Russell method (1966), for the 29 maize hybrids evaluated for five environments in Minas Gerais, in the 2014/2015 season

Cultivar	Type	Mean (β_0)	β_1	σ^2_d	R^2(%)
RB9004PRO	SC	11229	1.09^{ns}	3133101.76^{++}	83.89
SHS7920PRO	SC	10916	0.86^{ns}	69960.81^{ns}	93.02
BM709PRO2	SC	10842	1.05^{ns}	25344.87^{ns}	95.50
30A16PW	SC	10538	1.04^{ns}	2308096.55^{+}	85.62
BRS1055	SC	10413	1.15^{ns}	-429872.25^{ns}	98.03
P3862H	SC	10237	1.31*	-597268.58^{ns}	98.99
AG7098PRO2	SC	10198	1.26*	-677647.70^{ns}	99.20
FEROZViptera	DC	9846	0.98^{ns}	9315.50^{ns}	94.90
BM650PRO2	SC	9642	1.03^{ns}	-636357.08^{ns}	98.58
BM3063	TC	9615	0.99^{ns}	1668130.38^{+}	87.06
BG7049Hx	TC	9613	1.14^{ns}	-383313.48^{ns}	97.80
BM3066PRO2	SC	9570	1.22^{ns}	3259669.73^{++}	86.38
DKB390	SC	9440	1.02^{ns}	1825831.31^{+}	87.19
2B587PW	SC	9424	0.97^{ns}	551689.11^{ns}	91.95
2B512PW	TC	9336	0.81^{ns}	-165955.72^{ns}	94.08
2B810PW	SC	9257	1.12^{ns}	2304586.26^{+}	87.41
BM840PRO	SC	9170	1.12^{ns}	1678390.30^{+}	89.64
30F35	SC	9089	1.01^{ns}	4149347.19^{++}	78.27
20A55PW	TC	8854	0.81^{ns}	5334493.04^{++}	65.01
AS1573PRO	MSC	8629	0.82^{ns}	4744433.27^{++}	67.86
2B710PW	SC	8522	0.88^{ns}	-766126.79^{ns}	98.99
BRS3035	TC	8183	0.85^{ns}	121582.74^{ns}	92.58
BM820	SC	7835	1.16^{ns}	-461560.46^{ns}	98.18
BM207	DC	7810	1.06^{ns}	362942.76^{ns}	94.04
BRS3060	TC	7709	0.81^{ns}	1301865.92^{ns}	84.23
CARGO	DC	7640	0.65**	-456417.02^{ns}	94.30
BM915PRO	SC	7505	0.91^{ns}	4808234.22^{++}	72.19
DKB330PRO	SC	7253	1.06^{ns}	4966222.34^{++}	77.21
BRS1010	SC	6929	0.82^{ns}	159466.08^{ns}	91.78

^{ns}: not significant and **, *: significantly different to 1 by t-test at 1% and 5% probability respectively. $^{++}$, $^{+}$: significantly different to 0 by F-test at 1% and 5% probability respectively

In the AMMI analysis, the first two principal components (PC1 and PC2) explained 76.8% of the variation due to the hybrid x environment interaction. According to Silva *et al*. (2011), there is a greater capture of the percentage variation with the first few principal components, and as the number of selected axes increases, the percentage of "noise" also increases, reducing the predictive power of the analysis. There was 29% residual noise, reflecting the relevance of the graph. The graph was therefore interpreted employing only the biplot and the AMMI2 model. Evaluating maize hybrids in different environments in the State of Minas Gerais by AMMI analysis, Namorato *et al*. (2009) also used the AMMI2 model, as observation of the first two axes in that model ensured a better graphical display, however the model only captured 50.7% of the sum of squares of the genotype x environment interaction.

Interpretation of stability by the AMMI method was based on the distance to zero of the scores of points representing the hybrids and environments (Figure 1). A shorter distance indicates greater stability (DUARTE; VENCOVSKY, 1999). The hybrids that are positioned closer to the origin of the axes are SHS7920PRO, BM709PRO2, BRS1055, P3862H, AG7098PRO2, BM650PRO2, BG7049Hx, 2B710PW, BM820 and BM207. These hybrids contributed little to the total hybrid x environment interaction, and were considered more stable and to be of general adaptability, as they interacted less with the environments. However, the 2B710PW, BM820 and BM207 hybrids were not the most productive. Of the 29 hybrids under evaluation, 19 contributed the most to the hybrid x environment interaction, as they are the most distant from the source of the biplot and are therefore more unstable. All the environments being evaluated are distant from the origin of the axes, and contribute to the total hybrid x environment interaction. The adaptability of the hybrids in each crop environment was interpreted by observing the signs of the hybrid and environment scores. In AMMI analysis, when the vector that represents the cultivar on the Cartesian plane is close to the vector that represents a particular environment, it shows that the cultivar performs better in that environment compared to the other cultivars (MIRANDA *et al*., 2009). When the hybrids and environments are distant from the origin and close to each other, with scores of the same sign, this represents specific adaptability. In this way, the hybrids 20A55PW, BM915PRO and 30A16PW stood out in the Viçosa1 and Sete Lagoas environments. These environments were considered favourable by the Eberhart and Russell method (1966). The hybrids DKB330PRO and AS1573PRO display specific adaptability to the environment of São Miguel do Anta, considered unfavourable by the Eberhart and Russell method (1966).

In estimating individual broad-sense heritability (h^2_g) by the method of mixed models, total genetic dispersion is considered, which is relevant, since this research seeks to explore all the genetic variance between the hybrids (RESENDE; DUARTE, 2007). Estimated heritability was 0.70, considered of moderate magnitude for grain yield in maize (HALLAUER, MIRANDA FILHO; CARENA, 2010) (Table 4). The selection of maize hybrids based on predicted genotypic values is therefore reliable (TORRES *et al*., 2015). The estimation of accuracy, which measures the correlation between predicted values and actual values, was also high at 83.69%. It can therefore be inferred that the experimental precision was high (RESENDE, DUARTE, 2007), which

Figure 1 - AMMI biplot, with the first two principal components (PC1 and PC2) for grain yield (kg ha^{-1}) evaluated in 29 commercial maize hybrids in the 2014/2015 season, for five environments in Minas Gerais

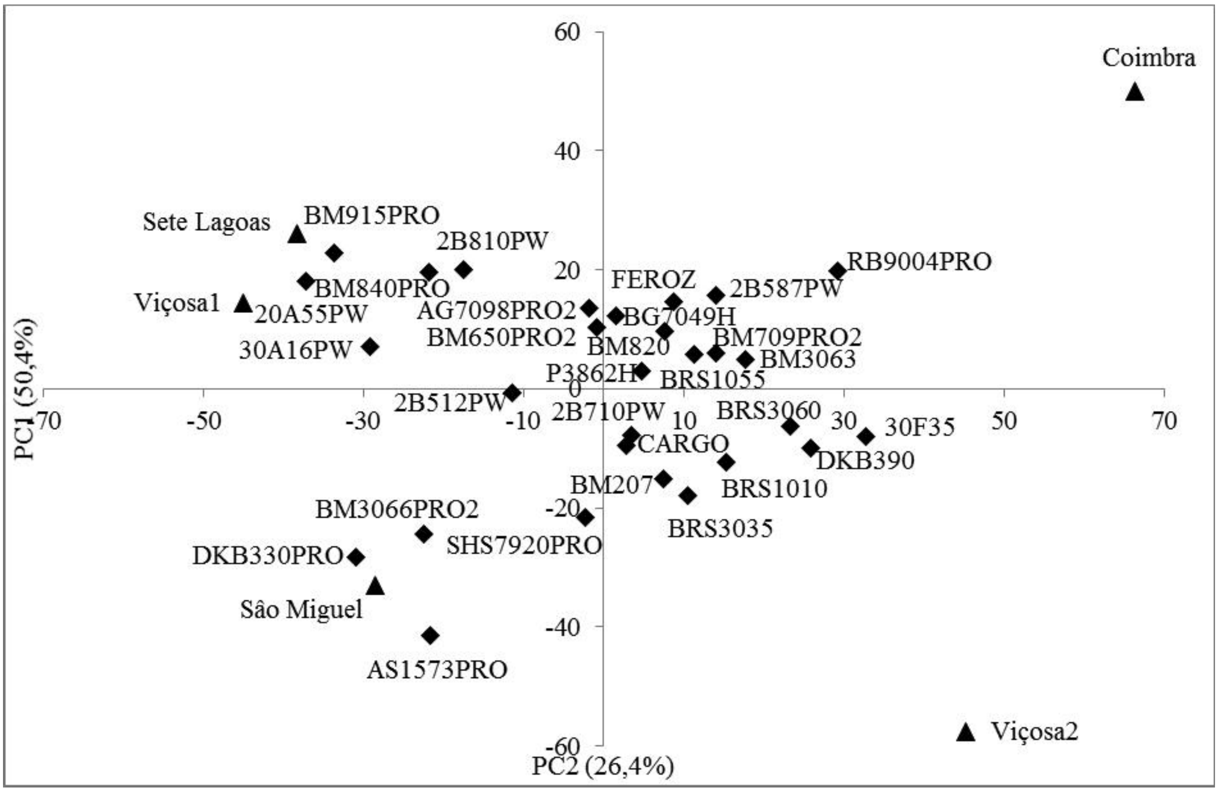


Table 4 - Estimates of the genetic parameters for grain yield (kg ha^{-1}) obtained with the REML/BLUP method, estimated in 29 maize hybrids in the 2014/2015 season, for five locations in Minas Gerais

Parameter	Estimate
Heritability (h^2)	0.70
Accuracy	0.84
Genotypic correlation between environments	0.45
CVe (%)	14.49
Overall Mean (kg ha^{-1})	9,146.26

agrees with the estimate of the experimental coefficient of variation (CVe = 14.49%). Results of similar magnitudes were obtained by Mendes *et al.* (2012) when estimating genetic parameters in 45 varieties of maize by the REML/BLUP method. Those authors found high experimental precision with a CVe of 13.6% and an estimated accuracy of 97%. According to Resende (2007), experimental precision can be considered excellent in experiments with precision values greater than 90%.

According to the confidence interval, the maize hybrids differed for grain yield, with hybrids RB9004PRO, SHS7920PRO, BM709PRO2, 30A16PW and BRS1055 displaying grain yields greater than 10,000 kg ha^{-1} (Figure 2). All are single hybrids and recommended for production systems that employ high technology.

Figure 3 shows the results of the MHPRVG*GM measures of adaptability and stability, penalising the hybrids for instability through the environments and at the same time benefitting their response capacity to environmental improvement (RESENDE, 2007). Despite the significant hybrid x environment interaction, hybrids of good adaptability and production stability were found. Hybrid RB9004PRO had the best performance, with a MHPRVG*GM value of 11,078 kg ha^{-1}, followed by SHS7920PRO and BM709PRO2, with 11,067 and 10,821 kg ha^{-1} respectively.

The MHPRVG method was also applied separately to the environments (Table 5). To this end, the five environments were divided into two groups, based on the average productivity of the hybrids in each location. The environments at Viçosa1, Viçosa2 and Sete Lagoas, with an average grain yield greater than the overall average (9,146 kg ha^{-1}), were considered favourable, and Coimbra and São Miguel do Anta, with averages below this value, were considered unfavourable. Estimated heritability for grain yield was greater in the group of favourable environments (0.64) than in the group of unfavourable environments (0.12). This same trend was seen for estimated accuracy, 0.80 and 0.35 respectively. That is, favourable conditions provide greater experimental precision than unfavourable conditions. Average productivity was 11,407 kg ha^{-1} for the favourable environments, and 5,755 kg ha^{-1} for the unfavourable environments.

The hybrids SHS7920PRO, RB9004PRO, BM709PRO2, 30A16PW, FEROZViptera, BM650PRO2, BRS1055, BM3063 and DKB390 displayed a productivity greater than the overall average in both the favourable and unfavourable environments; these were classified as having high adaptability. The hybrids 2B512PW, 2B587PW and 20A55PW were classified as having specific adaptability to unfavourable environments. The hybrids with specific adaptability to favourable environments were 2B810PW, AG7098PRO2, BG7049Hx, P3862H, BM840PRO and BM3066PRO2. The remaining hybrids did not achieve good performance in any of the environments, and were considered of minimal adaptability (Figure 4).

Figure 2 - Average genotypic values (VG) and their respective confidence intervals, for grain yield (kg ha^{-1}) in 29 commercial maize hybrids evaluated for five environments in Minas Gerais, in the 2014/2015 season

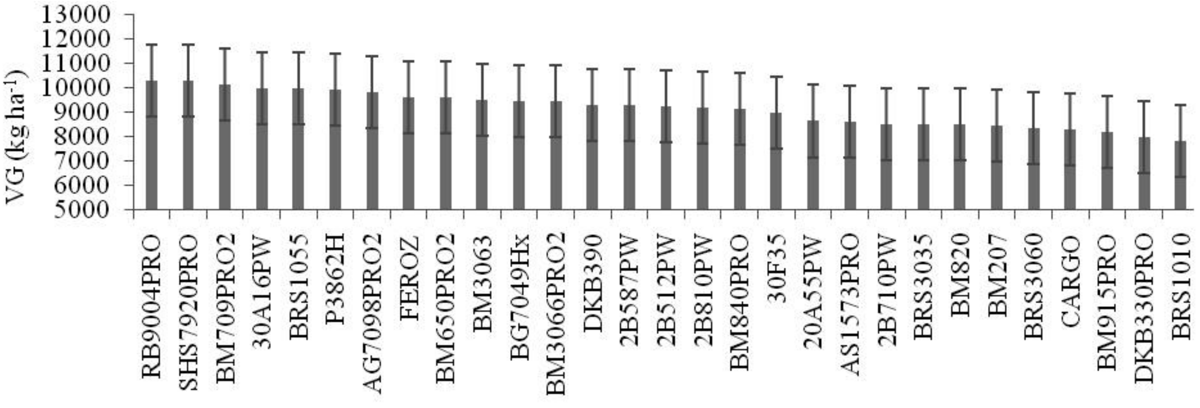


Figure 3 - Mean values for MHPRVG*GM in 29 commercial maize hybrids evaluated for grain yield (kg ha^{-1}) for five environments in Minas Gerais, in the 2014/2015 season

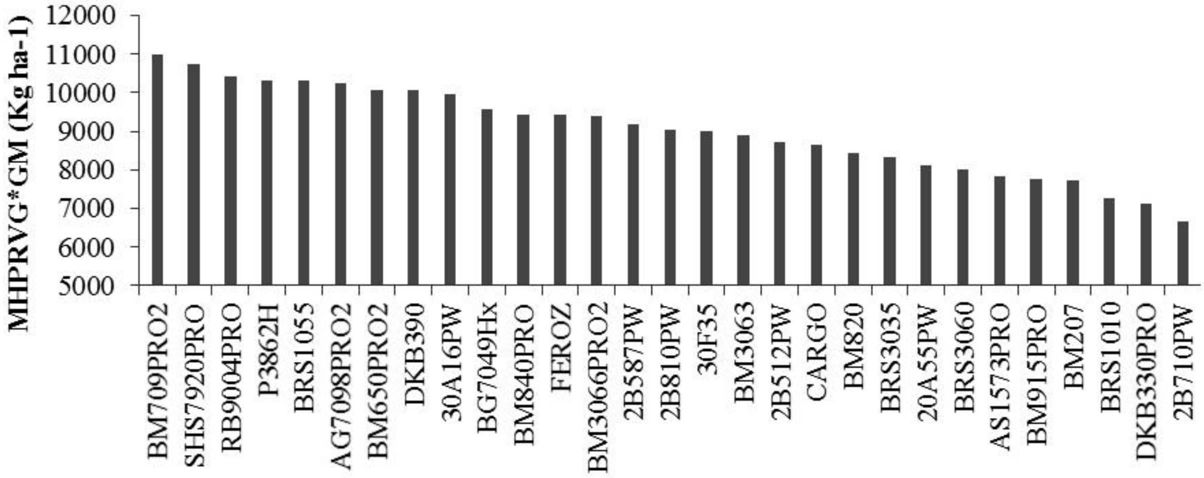
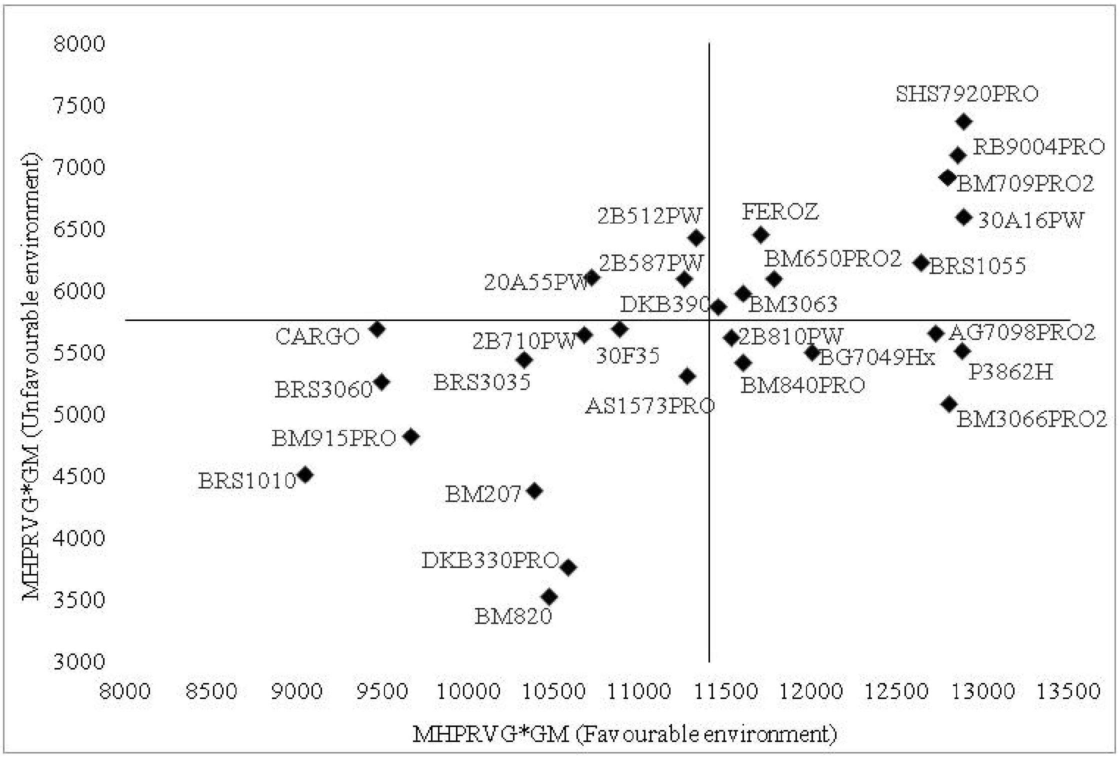


Table 5 - Estimates of the genetic parameters for grain yield (kg ha^{-1}) in favourable and unfavourable environments

Parameter	Favourable environment	Unfavourable environment
Heritability (h^2)	0.64	0.12
Accuracy	0.80	0.35
Genotypic correlation between environments	0.49	0.10
CVe (%)	10.70	25.60
Overall Mean (kg ha^{-1})	11,406.93	5,755.25

Figure 4 - Dispersion diagram of MHPRVG*GM for grain yield (kg ha^{-1}) in 29 maize hybrids in favourable and unfavourable environments



There were similarities seen in the three methods used for indicating hybrids. Among the most productive hybrids, stable and of broad adaptability, and recommended by the Eberhart and Russell method, SHS7920PRO, BM709PRO2, BRS1055 and BM650PRO2 were also indicated by the AMMI analysis and the REM/BLUP method. For favourable environments, the Eberhart and Russell and the mixed-model REM/BLUP methods recommended the P3862H and AG7098PRO2 hybrids. According to the results, it can be seen that the use of more than one method to estimate genetic parameters is a strategy that allows for greater reliability in the interpretation of data for the subsequent recommendation of cultivars. For Cruz, Carneiro and Regazzi (2014), some methods are seen as alternatives, while others are complementary and can be used together.

CONCLUSIONS

1. The Eberhart and Russell, AMMI and mixed-model methods show similar results in classifying maize hybrids of broad adaptability;
2. There is a difference in the indication of hybrids of specific adaptability to favourable and unfavourable environments, which justifies the use of more than one method of evaluation;
3. Based on the three methods, the hybrids SHS7920PRO, BM709PRO2, BRS1055 and BM650PRO2 display general adaptability in the environments under evaluation; the hybrids P3862H and AG7098PRO2 displayed specific adaptability to favourable environments.

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