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Adaptability and stability of corn hybrids in the off season across various agricultural regions in Brazil

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Genet. Mol. Res. 18 (3): gmr18193
Received October 29, 2019
Accepted April 08, 2019
Published July 19, 2019
DOI http://dx.doi.org/10.4238/gmr18193

ABSTRACT. We evaluated how genetic x environment (G x E) interactions affect grain productivity in corn hybrids grown in traditional and non-traditional environments in the off or “second” season. Adaptability and stability of the hybrids was examined by parametric, nonparametric and multivariate methods. In 2016, 24 hybrids were evaluated in seven environments, in 2017, 13 hybrids were evaluated in six environments. The environments were located between the regions of Southwestern and Southeast Goiás state; Triângulo Mineiro and Alto Paranaíba, in the western and northwestern regions of Minas Gerais state. In all trials, complete randomized blocks were adopted, and grain productivity was determined. The statistical analyses were performed with two different softwares: Estabilidade and Genes. It was observed that in both seasons, the locals considered as traditional corn cultivation in the off season Jataí-GO and Montividiu-GO gave the highest yields, with average yields higher than national averages, producing 3859 $kg.ha^{-1}$ in 2016 and 5562 $kg.ha^{-1}$ in 2017. The methods of Eberhart and Russell, Lin and Binns modified by Carneiro, Centroid and AMMI gave similar results in the rankings of the adaptation and stability of the hybrids. We concluded that the G x E interaction for grain productivity of corn hybrids grown in the off-season is complex in nature.

Key words: *Zea mays;* Interaction G x E; Adaptation

INTRODUCTION

Corn (*Zea mays*) due to its use for human and animal consumption and as raw material for industry is a major grain produced throughout the world (Moraes and Brito, 2011). It is grown throughout much of Brazil with various different production systems (Farinelli et al., 2003). Corn cultivation occurs practically throughout the country and production occurs at different periods of the year (agricultural crops) depending on the region (IBGE, 2015). The first crop or summer crop is grown mainly between September and March, while the second harvest in the off or “second” season is grown mostly between the months of January and May (Figueiredo et al., 2014).

The Cerrado is a Brazilian biome with immense social and environmental relevance. It stands out for its biodiversity and for being recognized as an agricultural expansion area. The increasing expansion of off season cropping in the States of Goiás and Minas Gerais is explained by the existence of suitable areas for crop cultivation during the off season; these areas are currently listed in new versions of published agricultural zoning (Embrapa, 2015).

Analyzing historical data, we observe that corn production in the off season was first recorded in the 1980s. In recent years, the off season is becoming more relevant (Landau et al., 2012) and it is possible to identify producers and traditional regions in the choice of summer crop soybean and corn as off season alternatives.

As soybean has become the main crop in many regions of the country due to its economic relevance, there has been a decrease in the area planted with summer corn, while the off season corn crop area has increased. In 2010/11, the area planted with corn crops in the off season exceeded the area planted in the summer; 2017/18 harvest estimates showed that off season corn crops were about two times larger than the summer harvest and accounted for 72.6% of total off season cereal crops cultivated in Brazil. National production of off season 2018 was estimated at more than 58 million tons, with an average productivity of 5029 $kg.ha^{-1}$, a value very close to the national average productivity for the cultivation of summer corn (CONAB, 2017).

Off season corn is developed in a non-irrigated system, and it is usually cultivated after early-cycle soybeans. The adoption of the no-tillage system in soybean straw, allows a reduction of the time between the harvest of the summer crop and sowing of the off season corn (Tsunechiro and Godoy, 2001); however, yield and production are strongly dependent on weather conditions.

The edaphoclimatic conditions of cultivation in the off season and summer vary considerably, but the vast majority of cultivars planted in the first harvest are also recommended for off season since corn breeding programs for off season are newer and less developed than those for summer corn breeding programs, and many cultivars from the breeding programs of the summer harvest show good performance and adaptation in the off season (Figueiredo et al., 2014). According to Fritsche-Neto et al. (2010) the success of a cultivar in the market is associated with high productive performance and the agronomic characteristics.

MATERIAL AND METHODS

The experiments were carried out in off season production environments in 2016 and 2017 in the southwest Goiás region, in representative sites for a traditional region (TRAD) in the cultivation of off season corn and in the southeast regions of Goiás, Triângulo Mineiro region, Alto Paranaíba region and northwest of Minas Gerais state, in representative sites for a non-traditional region (NTRAD) in the cultivation of off season corn (Table 1).

Table 1. Environments, states, medium altitudes (m), type and year off season corn.

#	Environment	State	Latitude	Longitude	Altitude (m)	Type	Year
A1	Araguari	MG	-18.6459014	-48.1979841	890	NTRAD	2016
A2	Catalão	GO	-18.1661075	-47.9444777	835	NTRAD	2016
A3	Indianopólis	MG	-19.0380618	-47.9178625	971	NTRAD	2016
A4	Jataí	GO	-17.8796049	-51.7206735	867	TRAD	2016
A5	Montividiu	GO	-17.4494387	-51.1760652	897	TRAD	2016
A6	Santana de Patos	MG	-18.832624	-46.5939409	851	NTRAD	2016
A7	Uberlândia	MG	-18.9127534	-48.275484	863	NTRAD	2016
A1	Catalão	GO	-18.1661075	-47.9444777	835	NTRAD	2017
A2	Jataí	GO	-17.8796049	-51.7206735	867	TRAD	2017
A3	Montividiu	GO	-17.4494387	-51.1760652	897	TRAD	2017
A4	Patos de Minas	MG	-18.5872582	-46.5146749	842	NTRAD	2017
A5	Uberlândia	MG	-18.9127534	-48.275484	863	NTRAD	2017
A6	Unaí	MG	-16.3596675	-46.902586	946	NTRAD	2017

NTRAD: Non-traditional; TRAD: Traditional

The hybrids evaluated in the harvests are listed in Table 2. A randomized complete block design with two replications was adopted. Each plot consisted of four rows of corn plants with 8.20 m long, spaced at 0.5 m, and the two central lines considered a useful plot.

The sowing was mechanized, in no-tillage system without soil development and sowing dates are within the main planting window in each region. The plant stand ranged from 50,000 to 65,000 plants ha^{-1}. The cultural tracts were performed according to the recommendation for the corn crop. The control of weed and pest plants was carried out through pre-emergent herbicide, post-emergence and insecticides application so that the corn crop could develop without interference.

Table 2. Corn hybrids sown in the experiments of off season in the years 2016 and 2017.

#	Hybrids	Off season	#	Hybrids	Year
1	3400RR2	2016	1	AG8677PRO3	2017
2	AG7088PRO3	2016	2	AG8690PRO3	2017
3	AG8070PRO3	2016	3	AG9050PRO3	2017
4	AG8677PRO3	2016	4	AS1555PRO3	2017
5	AG8700PRO3	2016	5	AS1633PRO3	2017
6	AS1581PRO	2016	6	AS1735PRO3	2017
7	AS1656PRO3	2016	7	AS1757PRO3	2017
8	AS1777PRO3	2016	8	AS1780PRO3	2017
9	DAS2B512PW	2016	9	DKB290PRO3	2017
10	DAS2B610PW	2016	10	DKB310PRO3	2017
11	DAS2B688PW	2016	11	DKB335PRO3	2017
12	DAS2B810PW	2016	12	DKB390PRO3	2017
13	DKB290PRO3	2016	13	H5	2017
14	DKB310PRO3	2016			
15	DKB390PRO2	2016			
16	DKB390PRO3	2016			
17	H1	2016			
18	H2	2016			
19	H3	2016			
20	H4	2016			
21	MG652PW	2016			
22	P30F53YHR	2016			
23	P3646LEP	2016			
24	RIB9110PRO	2016			

Grain yield was determined in each plot, and corrected for grain moisture as shown in the equation below, being then extrapolated to $kg.ha^{-1}$:

$$PF = PI\ \frac{100-UI}{100-UF} \qquad \text{(Eq. 1)}$$

where:
PF: corrected final weight of the sample;
PI: initial sample weight;
UI: initial moisture sample;
UF: final moisture sample (13%).

Data were subjected to individual analysis of variance according to the model:

$$Y_{ijk} = \mu + B_j + G_i\, B_j + \varepsilon_{ijk} \qquad \text{(Eq. 2)}$$

where:
μ: average mean;
B_j: plot j effect;
G_i: hybrid i effect;
ε_{ijk}: random error.

In each crop, after the analysis of individual variance, the ratio between the largest and lowest mean square of the residue was analyzed to test the homogeneity of the residual variances (Ramalho et al., 2012) and the degrees of freedom adjusted to carry out a joint analysis of variance (Cruz et al., 2012).

In the joint variance analysis, fixed effects were adopted for hybrids and cultivation sites in the following model:

$$Y_{ijk} = \mu + B/A_{jk} + G_i + A_j + GA_{ij} + \varepsilon_{ijk} \quad \text{(Eq. 3)}$$

where:
μ: average mean;
B/A_{jk}: effect of plot k in environment j;
G_i: hybrid i effect;
A_j: environment j effect;
GA_{ij}: interaction genotype-environment effect;
ε_{ijk}: random error.

Based on data from the analysis of the joint variance, the genotypic determination coefficient (H^2) was estimated, given by:

$$H^2 = \frac{\hat{\emptyset}_g}{QMG/r} \quad \text{(Eq. 4)}$$

$$\hat{\emptyset}_g = \frac{(QMG-QMR)}{r} \quad \text{(Eq. 5)}$$

where:
H^2: coefficient of genotypic determination;
$\hat{\emptyset}_g$: component genetic squared;
QMG: average square of genotypes;
QMR: average square of residue;
r: replicates number.

The study of the interaction G x E was performed by decomposition in a complex part between pairs of environments, as described by Cruz and Castoldi (1991), by the estimator:

$$C = \sqrt{(1-r)^3}\sqrt{Q_1 Q_2} \quad \text{(Eq. 6)}$$

In which, Q_1 and Q_2 correspond to the average squares of the genotypes in environments 1 and 2, respectively, and r the correlation between the means of the genotypes in both environments.

Once the interaction G x E was detected, the analysis of the phenotypic adaptability and stability was performed by the methods of Eberhart and Russel (1966), Lin and Binns (1988) Modified by Carneiro (1998), Centroid (Rocha et al., 2005) and AMMI (Zobel et al., 1988).

The analyses were performed using the computational program in Genetics and Statistics (GENES) (Cruz, 1997), and Estabilidade (UFLA, 2000).

RESULTS

It was observed in the analyses of individual variances for the year 2016 (Table 3) and for the year 2017 (Table 4) the opportunity to select hybrids with productive potential in most off season planting sites, whether these were traditional or non-traditional sites.

Table 3. Average productivity of environments, average squares, coefficient of variation and genotypic determination coefficient obtained in the evaluation of 24 genotypes of off season corn cultivated in seven environments in 2016.

#	Environment	QMG[1]	QMR[1]	CV(%)[1]	Yield (kg ha^{-1})
A1	Araguari-MG	1117430.10**	135321	10.005	3676.42
A2	Catalão-GO	890991.89**	49331.9	9.35	2376.24
A3	Indianopólis-MG	2411558.20**	242787	15.24	3233.09
A4	Jataí-GO	732573.60^{ns}	184623	6.39	6723.66
A5	Montividiu-GO	2436535.20**	316483	9.6	5861.08
A6	Santana de Patos-MG	1197852.73^{ns}	394703	19.51	3220.45
A7	Uberlândia-MG	461168.02^{ns}	346677	11.06	5325.27

NS: not significant; * and * *: significant at 5% and 1%, respectively, by the F test; QMG: Average square of genotypes; QMR: Average square of error; CV (%): coefficient of variation; [1]results obtained by individual analysis of variance.

Table 4. Average productivity of environments, average squares, coefficient of variation and genotypic determination coefficient obtained in the evaluation of 13 genotypes of off season corn cultivated in six environments in 2017.

#	Environment	QMG[1]	QMR[1]	CV(%)[1]	Yield (kg ha^{-1})
A1	Catalão-GO	435376.62**	113218.87	4.76	7062.06
A2	Jataí-GO	625832.52**	73806.35	3.43	7911.94
A3	Montividiu-GO	1261886.82^{ns}	1193793.1	10.41	10496.62
A4	Patos de Minas-MG	1260766.12**	269094.09	7.11	7300.31
A5	Uberlândia-MG	3461598.21**	317906.41	9.81	5746.14
A6	Unaí-MG	61513.22**	194862.86	9.51	4642.15

NS: not significant; * and * *: significant at 5% and 1%, respectively, by the F test; QMG: Average square of genotypes; QMR: Average square of error; CV (%): coefficient of variation; [1]results obtained by individual analysis of variance.

For the year 2016, the analyzed sites presented coefficient of variation (CV) between 6.39 and 19.51% (Table 3), while for the year 2017 the CV ranged from 3.43 to 10.41%.

Jataí-GO and Montividiu-GO, places classified as traditional in the planting of off season corn, were the sites that presented the highest productive potential in the two evaluated off seasons (Tables 3 and 4). The average yield of the experiments in these locations was similar to the values found by Silva et al. (2015) for the same region in the off season of 2013.

The ratios between the largest and the smallest mean square of the residue of the individual variance analyses for the years 2016 and 2017 (Tables 3 and 4) were 8 and 16.17, respectively. Therefore, to proceed with the joint analysis, the degree of freedom adjustments were made as suggested by Cruz et al. (2012).

The summary of the joint analysis of variance is found in Table 5 and Table 6, where it is noted significant effects for interaction between genotypes and environments at 1% probability level by F test. Silva et al. (2014) and Faria (2016) also reported significant occurrence of G x E interaction for grain yield.

Table 5. Analysis of variance combined for grain yield (kg.ha-1) evaluated in 24 genotypes of off season corn cultivated in seven environments in 2016.

Sources of variation Variação	Degrees of freedom	Mean square Médio
Plot/environment	7	1328592.18
Genotype (G)	23	2992026.99 **
Environment (E)	6	125931384.78 **
Interaction G x E	116	1240430.20 **
Error	131	293193.19
Mean		4345.17
CV (%)		12.46
H^2		58.54

* *: Significant to 1%, by F test; CV (%): coefficient of variation; H²: Genotypic determination coefficient.

Table 6. Analysis of variance combined for grain yield (kg.ha-1) evaluated in 13 genotypes of off season corn cultivated in six environments in 2017.

Sources of variation	Degrees of freedom	Mean square
Plot/environment	6	1608116.55
Genotype (G)	12	2698455.06^{ns}
Environment (E)	5	104310470.25**
Interaction G x E	32	1860800.79 **
Error	34	763299.42
Mean		7193.20
CV (%)		12.14
H^2		31.04

* *: Significant to 1%, by F test; CV (%): coefficient of variation; H²: Genotypic determination coefficient.

According to Table 7 and Table 8, it was observed that, in the two years, the interaction G x E was predominantly of a complex nature, because the decomposition of the interaction G x E, partly complex, by the method of Cruz and Castoldi (1991) showed that among the 21 pairs of environments was in the year 2016 and the 15 pairs of environments evaluated in 2017, only 3 environments in each year had decomposition of the interaction lower than 50%, indicating predominance of interaction of the simple type, and all other interactions were of a complex nature, demonstrating the importance of conducting adaptability and stability studies. Martinelli (2013) also verified interaction G x E Complex in the tests performed with corn in the off seasons 2012 and 2013.

Table 7. Estimation of the complex part of the decomposition of the interaction G x E (%) by the Cruz and Castoldi Method (1991) (below the diagonal) and the classification of the interaction between simple and complex (above the diagonal) in the analysis of 24 genotypes of off season corn cultivated in 7 Environments at 2016.

Environments	E 1	E 2	E 3	E 4	E 5	E 6	E 7
E 1	-	C	S	C	C	C	C
E 2	57.22	-	S	C	C	C	C
E 3	40.64	36.60	-	C	C	C	S
E 4	57.71	63.53	61.72	-	C	C	C
E 5	112.92	95.88	105.60	94.58	-	C	C
E 6	83.04	72.56	72.68	92.67	71.43	-	C
E 7	79.19	86.33	49.82	92.64	80.39	81.00	-

Environments: E1 (Araguari-MG) E2 (Catalão-GO), E3 (Indianopólis-MG), E4 (Jataí-GO), E5 (Monitividiu-GO), E6 (Santana de Patos-MG), E7 (Uberlândia-MG); C: Complex interaction; S: Simple interaction.

Table 8. Estimation of the complex part of the decomposition of the interaction G x E (%) by the Cruz and Castoldi Method (1991) (below the diagonal) and the classification of the interaction between simple and complex (above the diagonal) in the analysis of 13 genotypes of off season corn cultivated in 6 Environments at 2017.

Environments	E 1	E 2	E 3	E 4	E 5	E 6
E 1	-	C	C	S	S	C
E 2	94.34	-	C	C	S	C
E 3	88.50	87.78	-	C	C	C
E 4	31.57	67.26	109.61	-	C	C
E 5	19.37	48.27	88.58	55.35	-	C
E 6	67.53	88.07	90.99	72.83	61.79	-

Environments: E1 (Catalan-GO), E2 (Jataí-GO), E3 (Montividiu-GO), E4 (Patos de Minas-MG), E5 (Uberlândia-MG), E6 (Unaí-MG), C: complex interaction; S: Simple interaction.

In Tables 9 and 10, the environmental indexes (EI) and the classification of the studied environments are presented for the years 2016 and 2017, respectively. The EI is obtained by the difference between the means of tested genotypes in such environment and the average mean. It is observed that in the year 2016, 43% of the sites were classified as favorable to the planting of off season corn, while for the year 2017 this index was 50%. In the two years of testing, 100% of the environments of the region considered to be traditional for off season planting were evaluated as favorable, while most of the sites in the non-traditional regions were classified as unfavorable.

Table 9. Environmental index (EI), in the analysis of 24 genotypes of off season corn cultivated in 7 environments in 2016.

Environments	Average (kg.ha^{-1})	EI (kg.ha^{-1})	Classification
Araguari-MG	3676.42	-668.75	Unfavorable
Catalão-GO	2376.24	-1968.93	Unfavorable
Indianopólis-MG	3233.09	-1112.08	Unfavorable
Jataí-GO	6723.66	2378.49	Favorable
Montividiu-GO	5861.08	1515.91	Favorable
Santana de Patos-MG	3220.45	-1124.73	Unfavorable
Uberlândia-MG	5325.27	980.09	Favorable

Table 10. Environmental index (EI), in the analysis of 13 genotypes of off season corn cultivated in 6 environments in 2017.

Environments	Average (kg.ha^{-1})	EI (kg.ha^{-1})	Classification
Catalão-GO	7062.06	-131.14	Unfavorable
Jataí-GO	7911.94	718.74	Favorable
Montividiu-GO	10496.62	3303.42	Favorable
Patos de Minas-MG	7300.61	107.10	Favorable
Uberlândia-MG	5746.14	-1447.06	Unfavorable
Unaí-MG	4642.15	-2551.06	Unfavorable

Table 11 shows that 13 out of 24 genotypes tested in 2016 are of broad adaptation, but only four of these have high stability, while for the year 2017, 9 out of

13 genotypes tested (Table 12) are of wide adaptation and 7 out of 9 have high stability. Using the Eberhart and Russel Method (1966) for the analysis of off season hybrids, Faria (2016) also found that most hybrids showed high predictability of behavior and wide adaptability.

Table 11. Grain yield and stability and adaptability parameters by the methods of Eberhart and Russel (1966) and Lin and Binns (1988) Modified by Carneiro (1998), in 24 off season corn genotypes cultivated in seven environments in 2016.

Genotypes	Yield (kg ha^{-1})	Eberhart & Russel (1966)			Lin 7 Binns (1988) modified by Carneiro (1998)		
		B_{1i}	S^2di	R^2(%)	Pi general	Pi favorable	Pi unfavorable
3400RR2	4837.79	0.81*	98297.25^{ns}	90.53	752913.33	1276572.24	360169.15
AG7088PRO3	4635.31	0.81*	81129.06^{ns}	91.06	975452.40	1458751.41	612978.15
AG8070PRO3	5317.95	0.57**	95850.59^{ns}	82.77	688573.39	1604845.98	1368.95
AG8677PRO3	4656.2	1.06^{ns}	292185.77^{++}	89.65	890180.87	805279.92	953856.59
AG8700PRO3	4608.46	1.07^{ns}	53526.91^{ns}	95.43	903203.24	732665.73	1031106.38
AS1581PRO	3839.83	1.22*	163197.76^{+}	94.28	2371961.77	1723037.48	2858654.99
AS1656PRO3	3902.77	0.94^{ns}	343909.92^{++}	85.7	1985199.89	1917928.40	2035653.51
AS1777PRO3	4780.82	0.81*	400247.39^{++}	79.71	1108852.48	1995131.65	444143.1
DAS2B512PW	4828.59	0.96^{ns}	39595.59^{ns}	94.8	744785.07	941099.97	597548.89
DAS2B610PW	4647.16	1.01^{ns}	223572.28^{+}	90.34	1108595.60	1275995.32	983045.81
DAS2B688PW	3775.31	0.96^{ns}	280575.87^{++}	87.93	2563423.44	2566784.01	2560903.01
DAS2B810PW	3969.18	0.95^{ns}	446345.56^{++}	83.48	2305220.90	2705499.62	2005011.87
DKB290PRO3	4483.84	0.81*	34158.41^{ns}	93.14	1309738.04	2027084.66	771728.08
DKB310PRO3	4121.51	1.25**	-83537.77^{ns}	99.28	1737467.63	970629.28	2312596.4
DKB390PRO2	3889.03	1.17^{ns}	455508.91^{++}	88.17	2385011.41	1524632.72	3030295.43
DKB390PRO3	3525.23	1.16^{ns}	266256.67^{++}	91.59	3054931.56	2105831.35	3766756.72
H1	4011.25	0.78*	2196444.32^{++}	45.01	3298097.19	5446369.14	1686893.23
H2	4663.26	0.77**	796134.03^{++}	67.01	1625369.38	3163708.21	471615.25
H3	3988.98	1.35**	663693.02^{++}	88.00	2111070.38	699060.20	3170078.01
H4	4066.8	1.35**	-48402.64^{ns}	98.77	2074819.96	1193388.54	2735893.53
MG652PW	4725.48	1.04^{ns}	-2453.19^{ns}	96.7	744861.03	615514.54	841870.91
P30F53YHR	4100.48	0.92^{ns}	590712.44^{++}	78.83	1706610.80	1515332.37	1850069.62
P3646LEP	3980.48	1.17^{ns}	65977.51^{ns}	95.85	2031496.53	1421688.05	2488852.89
RIB9110PRO	4928.45	1.08^{ns}	1255089.11^{++}	72.92	656131.63	185392.01	1009186.34

NS: not significant; * and * *: significant at 5% and 1%, by T. NS Test: not significant; + and + +: Significant at 5% and 1% by F test; B_1i: Adaptability parameter; S² di: variance of regression deviations; R^2: Coefficient of regression determination.

The non-parametric method of Lin and Binns (1988) Modified by Carneiro (1998) allows analyzing the adaptation and stability of the genotypes by only one parameter (Pi), as shown in Tables 11 and 12. Considering the lowest estimates of general Pi, for the Year 2016 (Table 11) it was observed that among the 5 hybrids with higher productivity and general adaptation, RIB9110PRO and MG652PW has specific adaptation to favorable environments and AG8070PRO3, 3400RR2 and DAS2B512PW specific adaptation to unfavorable environments. Regarding the year 2017 (Table 12) among the 5 hybrids with higher productivity and general adaptation, the hybrids DKB335PRO3, AS1633PRO3, AS1735PRO3 and AS1557PRO3 also classified among the best in the specific adaptation to favorable environments and in the adaptation specific to favorable environments.

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The hybrid that presented the highest grain yield was the RIB9110PRO in the Montividiu-GO environment, reaching 8470 kg ha^{-1} in the off season of 2016, while in the production environment of Araguari-MG is among the hybrids that produced the least. This fact indicates that there is a complex type interaction between hybrids and production environments. (Table 13). This result is justified by the fact that Montividiu is a traditional region in the cultivation of off season corn, which indicates that there is historically the presence of edaphoclimatic conditions and the use of technologies that favor the best performance of hybrids. On the other hand, in the Araguari production environment, which is considered a non-traditional region for the cultivation of the off season corn, we have a lower productivity that is the result of a less favorable production environment for genotype expression.

Table 12. Grain yield and stability and adaptability parameters by the methods of Eberhart and Russel (1966) and Lin and Binns (1988) Modified by Carneiro (1998), in 13 off season corn genotypes cultivated in 6 environments in 2017.

Genotypes	Yield (kg ha^{-1})	Eberhart & Russel (1966)			Lin & Binns (1988) modified by Carneiro (1998)		
		B_{1i}	S²di	R²(%)	Pi general	Pi favorable	Pi unfavorable
AG8677PRO3	6999.83	0.74**	26624.39^{ns}	92.98	983810.00	1436981.30	530638.71
AG8690PRO3	6589.16	1.13^{ns}	-55524.87^{ns}	98.09	1623223.91	1085202.12	2161245.69
AG9050PRO3	7231.25	0.70**	311395.41^{+}	83.30	857513.01	1494987.21	220038.80
AS1555PRO3	6938.52	1.10^{ns}	218250.57^{ns}	93.85	1175117.29	1066828.02	1283406.55
AS1633PRO3	7755.53	0.93^{ns}	-65817.46^{ns}	97.43	156188.71	228581.30	83796.13
AS1735PRO3	7826.94	0.92^{ns}	379437.28^{+}	88.30	173203.03	229890.76	116515.31
AS1757PRO3	7477.22	0.91^{ns}	-104982.38^{ns}	98.23	422861.05	502580.03	343142.07
AS1780PRO3	7363.74	1.22*	547011.72^{++}	91.16	1007646.93	131584.42	1883709.44
DKB290PRO3	6874.52	1.16^{ns}	72711.44^{ns}	96.36	1251027.37	510506.78	1991547.96
DKB310PRO3	7093.27	1.27**	552355.24^{++}	91.67	846260.73	770398.23	922123.23
DKB335PRO3	7866.13	0.88^{ns}	212628.70^{ns}	90.82	119308.92	231588.63	7029.21
DKB390PRO3	6278.14	1.10^{ns}	907589.32^{++}	84.89	2600631.04	1920053.79	3281208.30
H5	7217.40	0.94^{ns}	195276.34^{ns}	92.19	854462.47	594384.44	1114540.50

NS: not significant; * and * *: significant at 5% and 1%, by T. NS Test: not significant; + and + +: Significant at 5% and 1% by F test; B_1i: Adaptability parameter; S ² di: variance of regression deviations; R^2: Coefficient of regression determination.

Table 13. Average yield ($kg.ha^{-1}$) of off season corn genotypes cultivated in 7 environments in 2016.

Genotypes	Locations						
	Araguari-MG	Catalão-GO	Indianopólis-MG	Jataí-GO	Montividiu-GO	Santana de Patos-MG	Uberlândia-MG
3400RR2	4539.41Ca	2809.17Da	4638.32Ca	6991.96Aa	6008.76Bc	3761.44Db	5115.48Cb
AG7088PRO3	3922.98Cb	2710.97Da	3656.83Cb	6703.21Aa	5905.06Ac	4537.68Ca	5010.44Bb
AG8070PRO3	5027.29Ba	3994.78Ca	4976.56Ba	7255.81Aa	5415.8Bd	4766.53Ba	5788.89Ba
AG8677PRO3	3884.09Bb	2635.85Ca	3041.65Cc	7274.29Aa	6976.69Ab	4071.44Ba	4709.42Bb
AG8700PRO3	3864.1Cb	2587.22Da	3071.05Dc	7094.91Aa	6784.51Ab	3752.01Cb	5105.47Bb
AS1581PRO	2836.6Dc	2121.25Db	1969.49Dd	7135.73Aa	5920.19Bc	2519.74Dc	4375.86Cb
AS1656PRO3	3372.09Cc	1444.94Db	2900.54Cc	5222.87Bb	6303.92Ac	3224.91Cb	4850.13Bb
AS1777PRO3	5131.94Ba	2640.86Da	4443.19Ca	7259.84Aa	5187.36Bd	3568.37Cb	5234.21Bb
DAS2B512PW	4418.16Ca	2596.36Da	4431.76Ca	7087.15Aa	6186.09Bc	3345.78Db	5734.86Ba
DAS2B610PW	3964.96Cb	2528.95Da	4410.44Ca	7121.7Aa	5733.05Bc	2758.2Dc	6012.81Ba
DAS2B688PW	3040.08Cc	2198.63Db	1621.93Dd	6275.3Ab	5043.64Bd	3489.17Cb	4758.43Bb
DAS2B810PW	3853.59Cb	2341.03Da	3501.29Cb	6692.44Aa	4734.88Bd	1685.2Dd	4975.88Bb
DKB290PRO3	3919.18Cb	3192.63Ca	3696.26Cb	6897.64Aa	5170.51Bd	3210.76Cb	5299.92Bb
DKB310PRO3	3123.29Cc	1722.29Db	2827.92Cc	6882.51Aa	6297.49Ac	2602Cc	5395.12Bb
DKB390PRO2	2820.13Bc	1639.76Cb	1603.43Cd	6081.98Ab	5764.06Ac	3361.64Bb	5952.22Aa
DKB390PRO3	2628.37Bc	1268.74Cb	1593.5Cd	5569.57Ab	5502.51Ad	2532.74Bc	5581.21Aa
H1	4353.9Ca	3169.17Da	3446.82Db	7380.9Aa	2855.57Df	1625.18Ed	5247.24Bb
H2	4446.73Ba	2650.48Ca	4240.72Ba	7072.52Aa	4124.93Be	3789.38Bb	6318.07Aa
H3	2854.74Cc	1952.39Db	1493.09Dd	6734.03Aa	7377.22Ab	2799.54Cc	4711.87Bb
H4	3224.29Cc	1495.26Db	2202.91Dd	7247.69Aa	5860.23Bc	2691.13Cc	5746.08Ba
MG652PW	3857.43Cb	2661.12Da	4014.85Cb	6979.11Aa	6722.93Ab	3215.06Db	5627.86Ba
P30F53YHR	2552.54Dc	1929.42Db	4061.9Cb	5454.87Bb	6389.13Ac	3021.56Dc	5293.96Bb
P3646LEP	3771.65Cb	1561.61Db	2042.32Dd	6461.57Aa	5930.65Ac	2887.6Cc	5207.99Bb
RIB9110PRO	2826.67Dc	3176.97Da	3707.55Cb	6490.32Ba	8470.86Aa	4073.7Ca	5753.08Ba

[1]averages followed by distinct letters, uppercase in the row and lowercase in the column, differ from each other by the Scott-Knott test at 5% probability.

In the off season of 2017, the hybrid AS1780PRO3 was the one that stood out in terms of productivity in the production environment of Montividiu-GO, reaching 11673 $kg.ha^{-1}$ (Table 14). In this same crop, Montividiu presented the best yields for the majority of hybrids, as shown in Table 14.

Table 14. Average yield ($kg\ ha^{-1}$) of off season corn genotypes cultivated in seven environments in 2017.

Genotypes	Locations					
	Catalão-GO	Jataí-GO	Montividiu-GO	Patos de Minas-MG	Uberlândia-MG	Unaí-MG
AG8677PRO3	6835.45Ba	8042Aa	9044.69Ab	7259.06Ba	6232.94Ca	4584.83Da
AG8690PRO3	6654.62Ba	7217.93Ba	10386.02Ab	6823.6Bb	4413.7Cb	4039.12Ca
AG9050PRO3	7626.7Ba	7123.45Ba	9274.06Ab	8019.55Ba	6659.56Ba	4684.17Ca
AS1555PRO3	7177.44Ba	6992.75Ba	11066.9Aa	6698.56Bb	4950.57Cb	4744.92Ca
AS1633PRO3	7550.42Ba	8103.04Ba	11016.56Aa	7694.71Ba	6926.04Ba	5242.42Ca
AS1735PRO3	7233.17Ca	8901.23Ba	10499.35Ab	8244.63Ba	7444.49Ca	4638.77Da
AS1757PRO3	7691.93Ba	7740.68Ba	10504.85Ab	7694.95Ba	6213.48Ca	5017.46Ca
AS1780PRO3	6957.12Ba	8199.75Ba	11673.81Aa	7699.25Ba	4336.32Cb	5316.19Ca
DKB290PRO3	6860.39Ba	8098.8Ba	10287.02Ab	7540.37Ba	4588.21Cb	3872.31Ca
DKB310PRO3	6639.24Ca	7857.57Ba	11619.36Aa	6365.75Cb	6606.31Ca	3471.4Da
DKB335PRO3	7497.74Ba	8453.02Ba	10953.68Aa	7426.06Ba	7616.91Ba	5249.38Ca
DKB390PRO3	6074.61Ca	7684.09Ba	10275.59Ab	5401.41Cb	3531.03Db	4702.11Da
H5	7008.02Ca	8440.97Ba	9854.2Ab	8036.1Ba	5180.27Db	4784.87Da

[1]averages followed by distinct letters, uppercase in the row and lowercase in the column, differ from each other by the Scott-Knott test at 5% probability.

The Centroid method consists in comparing the values and the Cartesian distance between the genotypes and ideal genotypes, designated as Ideotype, allowing the classification of these as the General adaptability, Specific adaptability to favorable environments, Specific adaptability to unfavorable and Poorly adapted environments (Rocha et al., 2005), as shown in Tables 15 and 16. In 2016 (Table 15), 38% of the hybrids were classified as General adaptability, indicating the possibility of recommendation for all tested environments. In the same year, 46% of the hybrids were classified as Specific adaptability to favorable and unfavorable environments and 16% of them were classified as Poorly adapted. In 2017, the hybrids classified as General adaptability were 38.5%, which indicates the possibility of being recommended for the total of tested environments. 38.5% of the hybrids were classified as Specific adaptability to favorable and unfavorable environments and 23% of the hybrids were classified as Poorly adapted. In line with the observed in this research, Faria (2016) using the Centroid method, observed that 72.4% of the genotypes evaluated in the off season of Minas Gerais in 2016, were classified with general adaptability.

According to Rocha et al. (2005), probability values near or higher than 0.50 indicate good reliability in the genotype groupings in relation to the ideotypes. In this study, the probability values that allowed the classification of the genotypes between the groups ranged from 0.06 to 0.45 in the year 2016 (Table 15) and 0.05 to 0.35 (Table 16).

Table 15. Grain yield and stability and adaptability parameters by the centroid method (Rocha et al., 2005), in 24 genotypes of off season corn cultivated in seven environments in 2016.

Genotypes	Average (kg.ha^{-1})	Classification	Prob (I)	Prob (II)	Prob (III)	Prob (IV)
3400RR2	4837.79	I	0.33	0.20	0.26	0.18
AG7088PRO3	4635.31	I	0.30	0.21	0.27	0.20
AG8070PRO3	5317.95	I	0.35	0.16	0.31	0.16
AG8677PRO3	4656.2	I	0.31	0.27	0.20	0.19
AG8700PRO3	4608.46	I	0.30	0.28	0.20	0.20
AS1581PRO	3839.83	II	0.19	0.32	0.18	0.29
AS1656PRO3	3902.77	II	0.22	0.28	0.21	0.27
AS1777PRO3	4780.82	III	0.29	0.19	0.30	0.20
DAS2B512PW	4828.59	I	0.33	0.23	0.23	0.19
DAS2B610PW	4647.16	I	0.29	0.25	0.24	0.21
DAS2B688PW	3775.31	IV	0.18	0.25	0.21	0.34
DAS2B810PW	3969.18	IV	0.20	0.23	0.24	0.31
DKB290PRO3	4483.84	III	0.25	0.22	0.28	0.23
DKB310PRO3	4121.51	II	0.21	0.35	0.18	0.24
DKB390PRO2	3889.03	II	0.19	0.32	0.18	0.29
DKB390PRO3	3525.23	IV	0.16	0.29	0.17	0.35
H1	4011.25	IV	0.18	0.19	0.29	0.32
H2	4663.26	III	0.24	0.19	0.33	0.22
H3	3988.98	II	0.19	0.43	0.15	0.21
H4	4066.8	II	0.20	0.35	0.17	0.26
MG652PW	4725.48	I	0.33	0.26	0.20	0.18
P30F53YHR	4100.48	II	0.24	0.28	0.22	0.25
P3646LEP	3980.48	II	0.20	0.31	0.19	0.28
RIB9110PRO	4928.45	I	0.37	0.28	0.17	0.16

Class I: High General adaptability (MAXF, maxd); Class II: Specific adaptability to favorable environments (MAXF, Mind); Class III: Specific adaptability to unfavorable environments (Minf, maxd); Class IV: Poorly adapted (Minf, Mind); Class V: High General adaptability (MEDF, medd); Class VI: Specific adaptability to favorable environments (MAXF, medd); Class VII: Specific adaptability to unfavorable environments (MEDF, Maxd); Prob: Probability.

Table 16. Grain yield and stability and adaptability parameters by the centroid method (Rocha et al., 2005), in 13 genotypes of off season corn cultivated in six environments in 2017.

Genotypes	Average ($kg.ha^{-1}$)	Classification	Prob(I)	Prob(II)	Prob(III)	Prob(IV)
AG8677PRO3	0.25	III	0.20	0.31	0.23	
AG8690PRO3	0.18	IV	0.28	0.19	0.34	
AG9050PRO3	0.28	III	0.19	0.31	0.20	
AS1555PRO3	0.23	IV	0.26	0.23	0.26	
AS1633PRO3	0.50	I	0.16	0.20	0.13	
AS1735PRO3	0.51	I	0.16	0.19	0.13	
AS1757PRO3	0.35	I	0.20	0.25	0.17	
AS1780PRO3	0.25	II	0.36	0.17	0.20	
DKB290PRO3	0.20	II	0.35	0.18	0.26	
DKB310PRO3	0.29	I	0.24	0.24	0.21	
DKB335PRO3	0.54	I	0.13	0.20	0.11	
DKB390PRO3	0.14	IV	0.22	0.17	0.44	
H5	0.27	II	0.29	0.21	0.22	
AG8677PRO3	69.998.258	III	0.25	0.20	0.31	0.23
AG8690PRO3	65.891.633	IV	0.18	0.28	0.19	0.34
AG9050PRO3	72.312.458	III	0.28	0.19	0.31	0.20
AS1555PRO3	69.385.208	IV	0.23	0.26	0.23	0.26
AS1633PRO3	77.555.283	I	0.50	0.16	0.20	0.13
AS1735PRO3	78.269.375	I	0.51	0.16	0.19	0.13
AS1757PRO3	74.772.242	I	0.35	0.20	0.25	0.17
AS1780PRO3	73.637.367	II	0.25	0.36	0.17	0.20
DKB290PRO3	68.745.158	II	0.20	0.35	0.18	0.26
DKB310PRO3	70.932.675	I	0.29	0.24	0.24	0.21
DKB335PRO3	78.661.292	I	0.54	0.13	0.20	0.11
DKB390PRO3	62.781.383	IV	0.14	0.22	0.17	0.44
H5	72.174.025	II	0.27	0.29	0.21	0.22

Class I: High General adaptability (MAXF, maxd); Class II: Specific adaptability to favorable environments (MAXF, Mind); Class III: Specific adaptability to unfavorable environments (Minf, maxd); Class IV: Poorly adapted (Minf, Mind); Class V: High General adaptability (MEDF, medd); Class VI: Specific adaptability to favorable environments (MAXF, medd); Class VII: Specific adaptability to unfavorable environments (MEDF, Maxd).

In order to infer about the stability of the genotypes by the AMMI analysis (Zobel et al., 1988), the first two principal components (CP1, CP2) were represented in the Cartesian plane, for the years 2016 and 2017 (Figures 1 and 2, respectively).

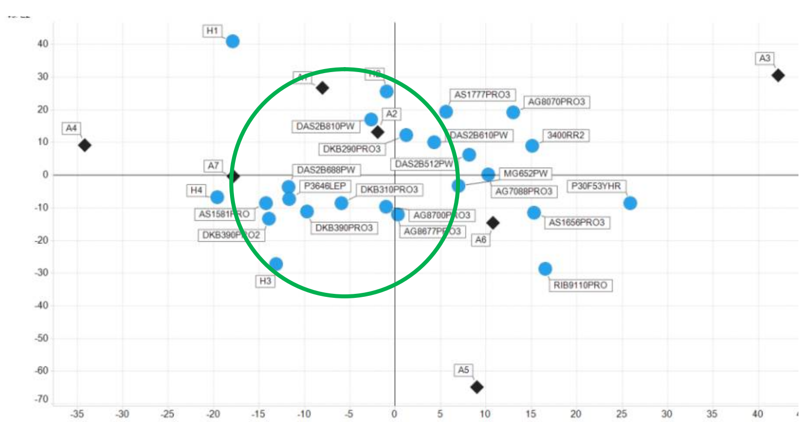

Figure 1. Plotting of the scores of the first two main components, according to the model AMMI 2 for grain yield, for 24 genotypes of off season corn in 2016.

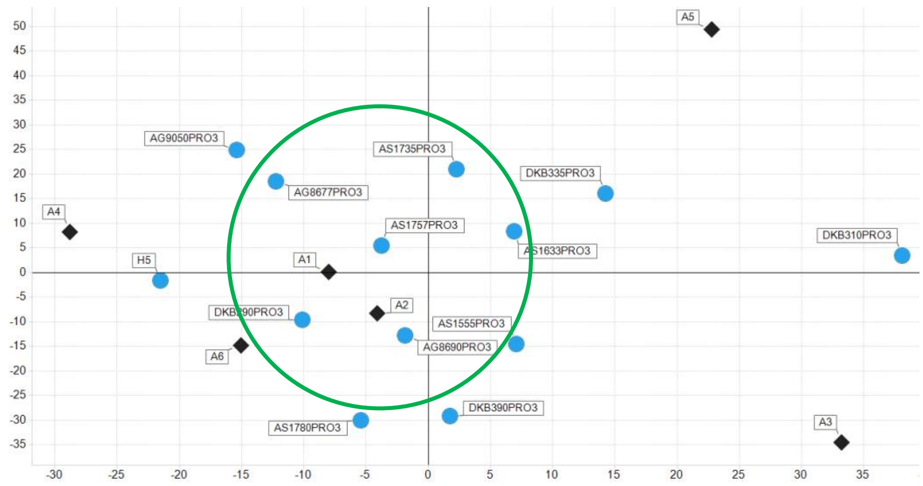

Figure 2. Plotting of the scores of the first two main components, according to the model AMMI 2 for grain yield, for 13 genotypes of off season corn in 2017.

For the AMMI analysis, the first two main components (CP1 and CP2) explained 73% of the variation due to the interaction G x E in the year 2016 and 78.9% of the variation due to the interaction G x E in the year 2017. According to Pereira et al. (2009), the first main components should explain above 70% of the sum of the squares of the interaction, to be considered satisfactory. When evaluating 29 corn hybrids in the off season of 2016, Faria (2016) observed values of 72.6% of CP1 and CP2 accumulated.

The interpretation of the stability by the AMMI method was performed from the distance of the representative points of the hybrids and environments to the zero score (Figure 1 and Figure 2). Thus, the shortest distance indicates greater stability (Duarte and Vencovsky, 1999).

The most distant hybrids of the axis, are those that contributed little to the interaction G x E total and were considered more stable and with general adaptability, because they interact less with the environments (Chaves, 2001). For the year 2016 (Figure 1), 2 of the hybrids that are positioned closest to the origin of the axes and were, therefore, classified as more stable and of general adaptability, are among the 5 most productive hybrids, for the year 2017 (Figure 2), this same proportion was 3 of the hybrids classified as more stable and of general adaptability and more productive. In 2016 (Figure 1), the most traditional environments were those that contributed to the G x E interaction, while for the year 2017 (Figure 2), there was a greater contribution of non-traditional region environments to the planting of off season corn in the interaction G x E, since these were farther away from the origin of the axes.

The results showed that the hybrid AG8700PRO3 showed high grain yield, wide adaptation and high stability in the 2016 crop, already in the harvest of 2017 the same occurred for the hybrid AS1757PRO3.

DISCUSSION

In the two years of testing evaluated in this study, the experimental precision was classified as medium to high through the coefficient of variation, which indicates the experimental precision quality. Experiments with low coefficients of variation, or high precision, are desired by the breeders, since they provide the obtaining of estimates of genetic parameters more reliable, or accurate, which are important in decision making process of the breeding program (Cargnelutti Filho et al., 2012). According to Pimentel-Gomes (1990), a CV (%) is considered low and with high precision (<10%); medium = (10 to 20%); high (20 to 30%); too high (>30%).

The coefficients of genotypic determination that express the proportion of phenotypic variability attributed to genetic causes were 58.54% for 2016 and 31.04% for 2017 (Tables 5 and 6), and therefore, of medium magnitude for the character grain production. According to Cruz et al. (2012), the genotypic determination coefficient is considered of high magnitude when it is above 70%.

The occurrence of G x E interaction is indicative of the differential behavior of the genotypes, in relation to grain yield, with environmental oscillation. In this context, the study of G x E interaction becomes important to determine its nature. Most quantitative traits, such as yield, are polygenic in nature and highly influenced by the environment. The G x E interaction strongly influences the expression of these quantitative traits (Schmildt et al., 2011).

Grain yield is one of the most highly valued traits by breeding programs. In general, one applies selection for traits indirectly related to yield; towards the end of the program, a higher selection index is applied to increase effectiveness in obtaining high yielding genotypes. The yield expression is controlled by quantitative or polygenic traits; i.e. it depends on the action of many genes. When the selective pressure is high at the beginning of the breeding program, some heterozygous inbred lines can be eliminated, affecting the number of superior lines reaching final trials.

One of the methods used in the evaluation of adaptability and stability is a method based on simple linear regression of Eberhart and Russel (1966). This method also allows one to classify the environments as favorable and unfavorable according to the environmental index. High adaptability and stability hybrids have better agronomic performance and commercial viability (Busanello, et al 2015)

When this index results in a negative value, it indicates that the environment is unfavorable and when the index is positive, the environment is classified as favorable. Favorable sites occur due to the influence of the environment, which, in the case of corn crop, probably went through some biotic or abiotic stress. Faria (2016) classified environments in favor of evaluating hybrids in the off season of Minas Gerais.

The Eberhart and Russel Method (1966) also allows the identification of genotypes with specific adaptation to favorable environments (B1 > 1) and unfavorable (B1 < 1). According to this method, the ideal genotype is the one that presents broad adaptation (B1 = 1) and high stability (variance of the deviations from the null regression). Regarding the simultaneous analysis of the adaptability and stability parameters ($\beta 1i$ and $\Sigma 2di$) obtained by this method, it was found that the majority of the hybrids showed high predictability of behavior and wide adaptability. Acording to Busanelo et al. (2015), in a study of stability and adaptability of corn hybrids in southern Brazilian regions, the yield magnitude of these hybrids is influenced positively by the ability to take advantage of predictable stimuli of environments.

This result confirms Montividiu as a favorable region for hybrid potential expression, reaffirming its position as a traditional region for off season corn cultivation. Duvick (2005) affirms that changes in cultural practices have been responsible for a significant portion of maize yield gains. This could be related to timeliness of planting and selection of adapted regions.

Environmental stratification analysis also allows you to make decisions about discards of environments, when there are technical problems or shortage of resources, and identify groups of environments where the G x E interaction may not be significant for the set of available genotypes (Cruz et al., 2012).

CONCLUSIONS

The genotype-environment interaction for grain yield in corn hybrids cultivated in the off season is of a complex type. In the years 2016 and 2017, there was high grain yield of corn in the corn off season in the environments of Jataí-GO and Montividiu-GO, both considered as traditional regions in the off season. In the off season of 2016, the hybrids DAS2B512PW, MG652PW and AG8700PRO3 showed high grain yield, wide adaptation and high stability. In the off season of 2017, the hybrids AS1633PRO3, AS1757PRO3 and DKB335PRO3 showed high grain yield, wide adaptation and high stability.

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