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Performance and stability of maize topcross hybrids from partly inbred lines

Desempenho e estabilidade de híbridos *topcrosses* de linhagens parcialmente endogâmicas de milho

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Abstract

Commercial hybrids are viable to generate base populations for obtaining new superior lines. Therefore, this study aimed to evaluate the performance and stability of maize topcross hybrids and select superior partly inbred lines. We evaluated 155 topcross hybrids of partly inbred lines crossed with an elite inbred line (tester) together with 14 commercial hybrids (2B688, AG7088, AS1575, DKB390, GNZ2005, GNZ8132, GNZ9501, GNZ9505, GNZ9548, GNZ9623, P30F35, P30F53, P30R50, and Penta) in Guarapuava-PR, Candói-PR, Guarda-Mor-MG, and Paracatu-MG (Brazil). The assessed variable was grain yield (GY), in kg ha^{-1}, at 13% moisture, being the plant stand corrected by covariance method. A variance analysis was carried out, testing both stability and adaptability. There were significant differences for all sources of variation. By considering the GY means of the genotypes in each environment, Candói (10,985 kg ha^{-1}) and Paracatu (10,917 kg ha^{-1}) were in the first group, while Guarda-Mor (10,448 kg ha^{-1}) was allocated in the intermediate group, and Guarapuava (10,159 kg ha^{-1}) formed the group of lower GY means. None of the topcrosses stood out in any of the four environments, which may be related to the differences in climate and altitude between environments. Despite of this fact, lines 9, 13, 39, 40, 60, 93, 108, 179, 184, 189, 194, 211, 212, 213, 216, 217, 235, 243, 245, and 253 excelled as promising and should follow the process of inbreeding, in addition to the topcrosses 87, 144, 179, and 211, which also stood out for stability and adaptability in these environments.
Key words: *Zea mays* L. Adaptability. Annicchiarico. Maize breeding. Genotype-environment interaction.

Resumo

Os híbridos comerciais são viáveis para gerar populações-base para obter novas linhagens superiores. Portanto, o objetivo deste trabalho foi avaliar o desempenho e estabilidade de híbridos *topcrosses* de milho e selecionar híbridos superiores e/ou linhagens parcialmente endogâmicas com potencial superior. Foram avaliadas 155 linhagens parcialmente endogâmicas em cruzamentos topcrosses com uma linhagem elite (testador) juntamente com 14 híbridos comerciais (2B688, AG7088, AS1575, DKB390, GNZ2005, GNZ8132, GNZ9501, GNZ9505, GNZ9548, GNZ9623, P30F35, P30F53, P30R50 e Penta) em Guarapuava-PR, Candói-PR, Guarda-Mor-MG e Paracatu-MG. Foi avaliado a produtividade de

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grãos (GY) em kg ha^{-1} com 13% de umidade em que o estande de plantas foi corrigido pelo método da covariância. Fez-se análise de variância dos dados e de estabilidade e adaptabilidade. Houve efeito significativo para todas as fontes de variação. Considerando a média de GY em kg ha^{-1} dos genótipos em cada ambiente, Candói (10,985 kg ha^{-1}) e Paracatu (10,917 kg ha^{-1}) foram alocados no primeiro grupo, enquanto Guarda-mor (10,448 kg ha^{-1}) foi alocado no grupo intermediário e Guarapuava (10,159 kg ha^{-1}) formou o pior grupo de médias. Não houve híbridos *topcrosses* que se destacaram nos quatro ambientes. Apesar deste fato, as linhagens 9, 13, 39, 40, 60, 93, 108, 179, 184, 189, 194, 211, 212, 213, 216, 217, 235, 243, 245 e 253 são promissoras e devem seguir no programa de melhoramento no processo de endogamia e os híbridos *topcrosses*87, 144, 179 e 211também se destacam por estar entre os melhores em mais de dois ambientes, sendo estáveis e adaptados e podem ser utilizados para cultivo nestes ambientes.

Palavras-chave: *Zea mays* L. Adaptabilidade. Annicchiarico. Interação genótipos x ambientes. Melhoramento do milho.

Introduction

Despite the high yield potential of the available genotypes, maize has low yields in Brazil since 60% are single hybrids (CRUZ et al., 2014a), which present high seed production cost, making less-technified producers use genotypes with lower potential (PATERNIANI et al., 2010).

The time spent to obtain partly inbred lines is shorter than that to obtain highly inbred lines. Furthermore, partly inbred lines are more vigorous and productive than are inbred lines, thus being able to generate high yield hybrids within a reduced time and lower costs, which are features acquired and evaluated in the development of topcross hybrids (FERREIRA et al., 2009; GUEDES et al., 2011; PATERNIANI et al., 2010). Therefore, commercial hybrids are viable to generate base populations for obtaining new lines (FERREIRA et al., 2010; PATERNIANI et al., 2010; OLIBONI et al., 2013).

Genotype x environment interactions are quite intense in maize hybrids (OLIBONI et al., 2013; PFANN et al., 2009) and restrict selection and recommendation of genotypes. In this sense, studying the stability and adaptability of a genotype is important for its selection and recommendation (ROCHA et al., 2007). These studies can be performed in several manners and most of them complement or supersede the generated information (CARGNELUTTI FILHO et al., 2009). The method by Annicchiarico (1992), which was modified by Schmidt and Cruz (2005), brings together concepts of stability and adaptability into a single parameter (SILVA et al., 2008), besides dividing the environmental effect into favorable, unfavorable, and general environment, providing a reliability index (ωi) for a genotype in each case (CRUZ et al., 2014b).

According to Cruz and Carneiro (2006), the above-mentioned method can be applied to only a few environments. An advantage of this method is its easy interpretation, wherein the most stable genotypes are also the most productive (PEREIRA et al., 2009). The stability and adaptability concepts based on variance analysis has been reported by diverse authors, such as Schmidt et al. (2011) on the phenotypic stability of maize genotypes, Condé et al. (2010) on the phenotypic stability of wheat genotypes, and Barros et al. (2012) on the adaptability and stability of soybean genotypes.

This study aimed to evaluate the stability and adaptability for maize grain yield of topcrosses of partly inbred S_2 lines in four different environments, and select promising lines and hybrids.

Material and Methods

A commercial maize single-cross hybrid, Penta, was used to generate a base population, obtaining 155 S_2 lines. These lines were crossed with a narrow genetic base tester. The tester consisted of a highly inbred line from Geneze Sementes® germplasm. This inbred line belongs to a heterotic group with tolerance to *Cercospora zeae-maydis* and to *Exserohilum turcicum*, high yield, early maturity, flint maize seed, and being adapted to the tropical high-altitude climate. Penta has early maturity, orange and flint maize seed, and shows good sanity of leafs and ears.

All the 155 topcrosses and 14 commercial hybrids – which were used as checks (2B688, AG7088, AS1575, DKB390, GNZ2005, GNZ8132, GNZ9501, GNZ9505, GNZ9548, GNZ9623, P30F35, P30F53, P30R50, and Penta), amounting 169 treatments, were assessed in 4 environments under a 13x13 triple lattice design. Each plot consisted of 5-m long rows spaced 0.8 apart, with a final stand of 62,500 plants ha^{-1}.

The experiments were performed in the cities of Guarapuava (25º21'S, 51º31'W, and 1,100 m altitude) and Candói (25º62'S, 52º02'W, and 900 m altitude) (Paraná state), and in the cities of Guarda-Mor (17º46'S, 47º05'W, and 600 m altitude) and Paracatu (17º13'S, 46º52'W, and 680 m altitude) (Minas Gerais state), Brazil. The cities of Guarapuava and Candói are characterized by a Cfb climate type and a dystroferric Dark-Red Latosol (Oxisol). Yet the cities of Paracatu and Guarda-Mor are under an Aw climate and with dystroferric Yellow Latosol (Oxisol) (KOTTEK et al., 2006).

Stater fertilization was applied using 350 kg ha^{-1} of NPK fertilizer (08-30-20) and side-dressings with 140 kg ha^{-1} nitrogen, using urea (45% N), divided into two applications at 4- and 6- leaf stages.

Grain yield was assessed after seed samples had been equilibrated to 13% moisture content, in kg ha^{-1}, and plant stand corrected by the covariance method proposed by Ramalho et al. (2012). The data were submitted to Bartlett's and Shapiro-Wilk's tests for homogeneity of variance and normality. Thereafter, the data were subjected to individual analysis of variance for each environment, and then a joint variance analysis was performed considering a fixed model for genotypes and environments.

For the joint analysis of variance, we used the method developed by Annicchiarico and modified by Schmildt and Cruz (2005). This method provides a statistical breakdown of the sum of squares of the effects of environments and Genotype x environment interaction into environmental effects on each genotype through reliability index (ωi). Thus, the higher the index, the greater the recommendation confidence level (CRUZ; CARNEIRO, 2006).

At first, the index is calculated by transforming the mean of each genotype, in each environment, into percentage values. From these estimates are obtained the reliability indexes for general adaptation (ω_{ig}), favorable (ω_{if}), and unfavorable (ω_{iu}) environments.

Reliability index for general adaptation (ω_{ig}):

$$\omega_{ig} = \bar{Y}_{i.} - Z_{(1-\alpha)}(\hat{\sigma}_{i.})$$

Reliability index for favorable environments (ω_{if}):

$$\omega_{if} = \bar{Y}_{if} - Z_{(1-\alpha)}(\hat{\sigma}_{if})$$

Reliability index for unfavorable environments (ω_{iu}):

$$\omega_{id} = \bar{Y}_{id} - Z_{(1-\alpha)}(\hat{\sigma}_{iu})$$

Wherein:

(ω) = reliability index.

Yi = Percentage mean for each genotype.

$Z_{(1-\alpha)}$ = Standardized value of normal distribution at which cumulative distribution function is equal to (1 α), with a significance level (α) of 0.25.

$\hat{\sigma}_{i.}$ = Standard deviation.

The lattice experimental design showed poor efficiency; therefore, the analysis of variance was performed under a randomized block design. The means were grouped by Scott-Knott test (p<0.05), and the phenotypic analysis of stability was performed by the Annicchiarico method modified by Schmildt and Cruz (2005). The analysis was performed using the GENES software (CRUZ, 2013).

Results and Discussion

The genotypes differed significantly (p≤0.01) for grain yield (GY), showing the genetic variability among topcrosses. Such variability can be assigned to the different S_2 lines deriving from Penta hybrid (Table 1), enabling the selection of superior S_2 lines and keeping them in inbreeding process, or using these genotypes as hybrids of partly inbred lines. These results corroborate those obtained by Oliboni et al. (2013) and Pfann et al. (2009), who highlighted the potential of Penta hybrid as base population.

Table 1. Joint analysis of variance for grain yield (GY – kg ha^{-1}) of 155 topcrosses and 14 checks assessed in the environments Guarapuava-PR, Candói-PR, Guarda-Mor-MG, and Paracatu-MG, UNICENTRO, 2016.

Source of Variation	DF	Mean Square	
		GY (kg ha^{-1})	
Blocks/Environments	8	2,548,015.85	
Genotypes (G)	168	9,109,883.91	**
Environments (E)	3	78,354,396.18	**
G x E	504	4,782,311.88	**
Error	1344	495,264.58	
Mean		10,627,16	
CV (%)		6,62	

** Significant at 1% probability by the F test.

There was a significant effect (p≤0.01) of environments and genotype x environment interactions (Table 1), showing that each environment promoted different GY expressions, besides ratifying the varying behavior of genotypes under environmental variations. By assessing GY of maize topcrosses, other authors have found significant effects of genotypes, environments, and interactions between them (FERREIRA et al., 2009, 2010; MARCONDES et al., 2015a, 2015b; PATERNIANI et al., 2006, 2010). This result reveals the need for a more detailed study to identify topcrosses displaying higher phenotypic stability. Genotypes x environment interactions are very important for GY since not all genotypes are adapted to all environments; therefore, this interaction should be thoroughly studied to identify genotypes with greater stability in most of the environments, in addition to choosing genotypes with a greater adaptability to a specific environment.

Considering the GY component for genotypes in each environment, Candói (10,985 kg ha^{-1}) and Paracatu (10,917 kg ha^{-1}) were in the first group, Guarda-Mor (10,448 kg ha^{-1}) was allocated in the intermediate group, and Guarapuava (10,159 kg ha^{-1}) formed the group of lower GY means (Table 2). Oliboni et al. (2013) evaluated diallel crosses among commercial hybrids, among which Penta showed general combining ability (GCA) negative for grain yield in Guarapuava and positive in Candói; thus, explaining the results we obtained in these both environments. Pfann et al. (2009) assessed commercial hybrids in diallel crosses and reported a positive and significant effect of GCA for grain yield of Penta hybrid in two environments within Paraná State, showing the possibility of extracting superior inbred lines from this hybrid.

The group with the highest means in Guarapuava encompassed 6.5% of the topcrosses (142, 152, 183, 189, 52, 9, 98, 193, 43, and 108) and the check GNZX8132 (12,628 kg ha^{-1}). Yet the second group allocated 14% of the topcrosses (248, 150, 240, 13, 211, 179, 3, 82, 137, 155, 72, 29, 33, 78, 48, 221, 60, 26, 65, 200, 144, and 21) along with the check GNZ2005 (11,226 kg ha^{-1}); those genotypes overcame the other checks (Figure 1A), indicating their high genetic value. The two best performance groups comprised 20.5% of the topcrosses, being similar to the results obtained by Paterniani et al. (2006), who evaluated a topcross of partly inbred lines from commercial hybrids.

Table 2. Mean grain yield (GY – kg ha^{-1}), class and index of Annicchiarico for the four assessed environments, UNICENTRO, 2016.

Environments	GY		Class	Index
Guarapuava	10,159	c	Unfavorable	-468
Candói	10,985	a	Favorable	358
Guarda-Mor	10,448	b	Unfavorable	-179
Paracatu	10,917	a	Favorable	290
Mean	10,627			
Standard Deviation	393			

Means followed by the same letter do not differ from each other by the Scott-Knott's test at 5% probability.

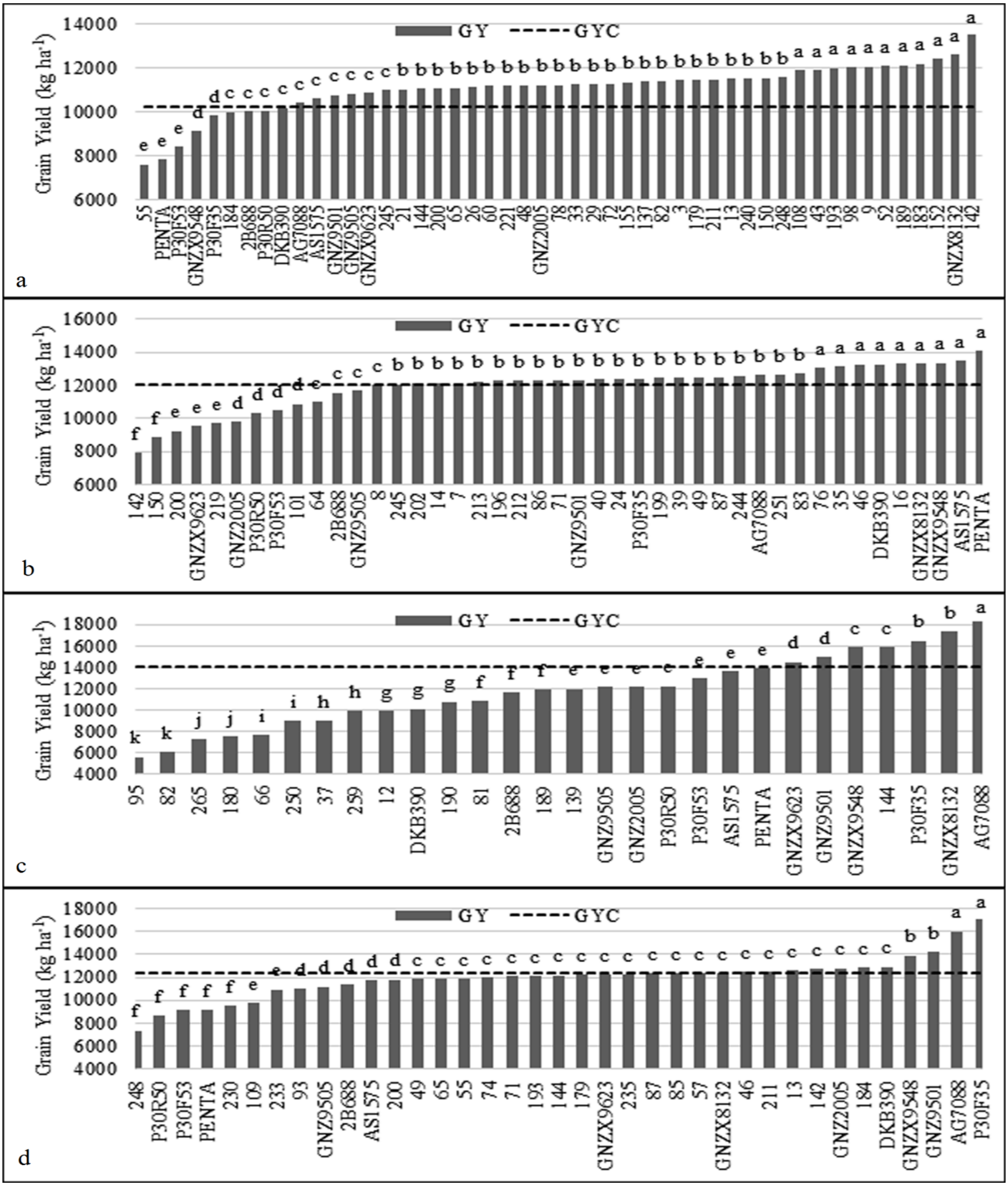
In Candói, the group with the highest means included the topcrosses 16 (13,282 kg ha^{-1}), 46 (13,259 kg ha^{-1}), 35 (13,111 kg ha^{-1}), and 76 (13,057 kg ha^{-1}), corresponding to 2.5% of all topcrosses, besides the checks Penta, AS1575, GNZX9548, GNZX8132, and DKB390. Furthermore, the second group contained 11.5% of the topcrosses (251, 244, 87, 49, 39, 199, 24, 40, 71, 86, 212, 196, 213, 7, 14, and 202) and the checks AG7088 (12,632 kg ha^{-1}), P30F35 (12,393 kg ha^{-1}), and GNZ9501 (12,332 kg ha^{-1}) (Figure 1B).

In Guarapuava, 47% of the topcrosses were more productive than the average of all checks (10,215 kg ha^{-1}) (Figure 1A), while in Candói 23 topcrosses (15%) presented a GY above the average of the checks (12,014 kg ha^{-1}) (Figure 1B). This outcome validates the potential of the genotypes evaluated in Guarapuava and in Candói environments, and the potential of selecting the best partly inbred lines to generate superior hybrids.

In Guarda-Mor, the checks AG7088 (18,257 kg ha^{-1}), GNZX8132 (17,347 kg ha^{-1}), and P30F35 (16,494 kg ha^{-1}) remained isolated in the first and second groups, displaying the best GY means, respectively. The third group was formed by topcross 144 (15,867 kg ha^{-1}) and the check GNZX9548 (15,855 kg ha^{-1}), whereas the fourth group contained GNZ9501 (14,966 kg ha^{-1}) and GNZX9623 (14,490 kg ha^{-1}), being better than the other checks and topcrosses (Figure 1C). In this environment, only the topcross 144 exceeded the GY average of checks (14,014 kg ha^{-1}) (Figure 1C), indicating the low performance of topcrosses to the detriment of the checks.

In Paracatu, none of the topcrosses was included in the first and second groups with the highest means, in which the checks P30F35 (17,124 kg ha^{-1}), AG7088 (16,012 kg ha^{-1}), GNZ9501 (14,248 kg ha^{-1}), and GNZX9548 (13,902 kg ha^{-1}) were grouped (Figure 1D). The third group included 11% of the topcrosses (184, 142, 13, 211, 46, 57, 85, 87, 235, 179, 144, 193, 71, 74, 55, and 65) and the checks DKB390 (12,922 kg ha^{-1}), GNZ2005 (12,797 kg ha^{-1}), GNZX8132 (12,392 kg ha^{-1}), and GNZX9623 (12,241 kg ha^{-1}) (Figure 1D). Special emphasis should be given to the topcrosses 184, 142, 13, 211, 46, 57, and 85 (4.5% of all topcrosses) whose GY means exceeded the average of the checks (12,344 kg ha^{-1}) (Figure 1D).

Figure 1. Summary of the highest and lowest means of grain yield (GY) for 155 topcrosses, grain yield means of the check (GYC) and 14 other checks in the environments of Guarapuava (A), Candói (B), Guarda-Mor (C), and Paracatu (D), UNICENTRO, 2016.



Mean followed by the same letter belongs to the same group according to the Scott-Knott's test at 5% probability.

In the two environments located in Minas Gerais state, most of the topcrosses presented GY means below those of the checks (Figure 1C and 1D). This result might have occurred because the genotypes were obtained from Penta hybrid, which is adapted to the central south of Parana state, where the cities of Candói and Guarapuava are located, as evidenced by Oliboni et al. (2013) and Pfann et al. (2009).

None of the topcrosses stood out in any of the four environments. It might be related to both climate and altitude differences. Added to this, one must point out that each topcross has a genetic potential to specific environments, and that only the check GNZAX8132 had high performance in all environments (Figure 1). In addition to improving the selection of topcrosses from S_2 lines, the evaluation of the interaction between environment and genotype makes the work of breeders more precise, compelling the use of alternative methods to identify genotypes with high genetic potential (CRUZ et al., 2014b).

The Annicchiarico analysis of stability, modified by Schmildt and Cruz (2005), ranked Guarapuava (index = –468) and Guarda-Mor (index = –179) as unfavorable environments, whereas Candói (index = 358) and Paracatu (index = 290) were ranked as favorable ones (Table 2). The average GY of the environments was 10,627 kg ha^{-1}; however, only in Guarapuava the GY mean was above standard deviation (393 kg ha^{-1}), being below the average of the other environments.

According to the analysis of general adaptation, 32 topcrosses and 11 checks obtained reliability indexes (ωi) above 100% regarding GY. Therefore, these topcrosses and checks are genotypes with great phenotypic stability (Figure 2). For unfavorable environment, 48 topcrosses and 11 checks presented ωi above 100%; whereas, for favorable environment, 51 topcrosses and 9 checks had ωi above 100% (Figure 2). The index ωi determines the risk of choosing a particular genotype by comparing the averages of other genotypes used in different environments. The higher the ωi is above 100%, the greater the reliability and the larger the chances of success in choosing a particular genotype for different environments (CRUZ et al., 2014b).

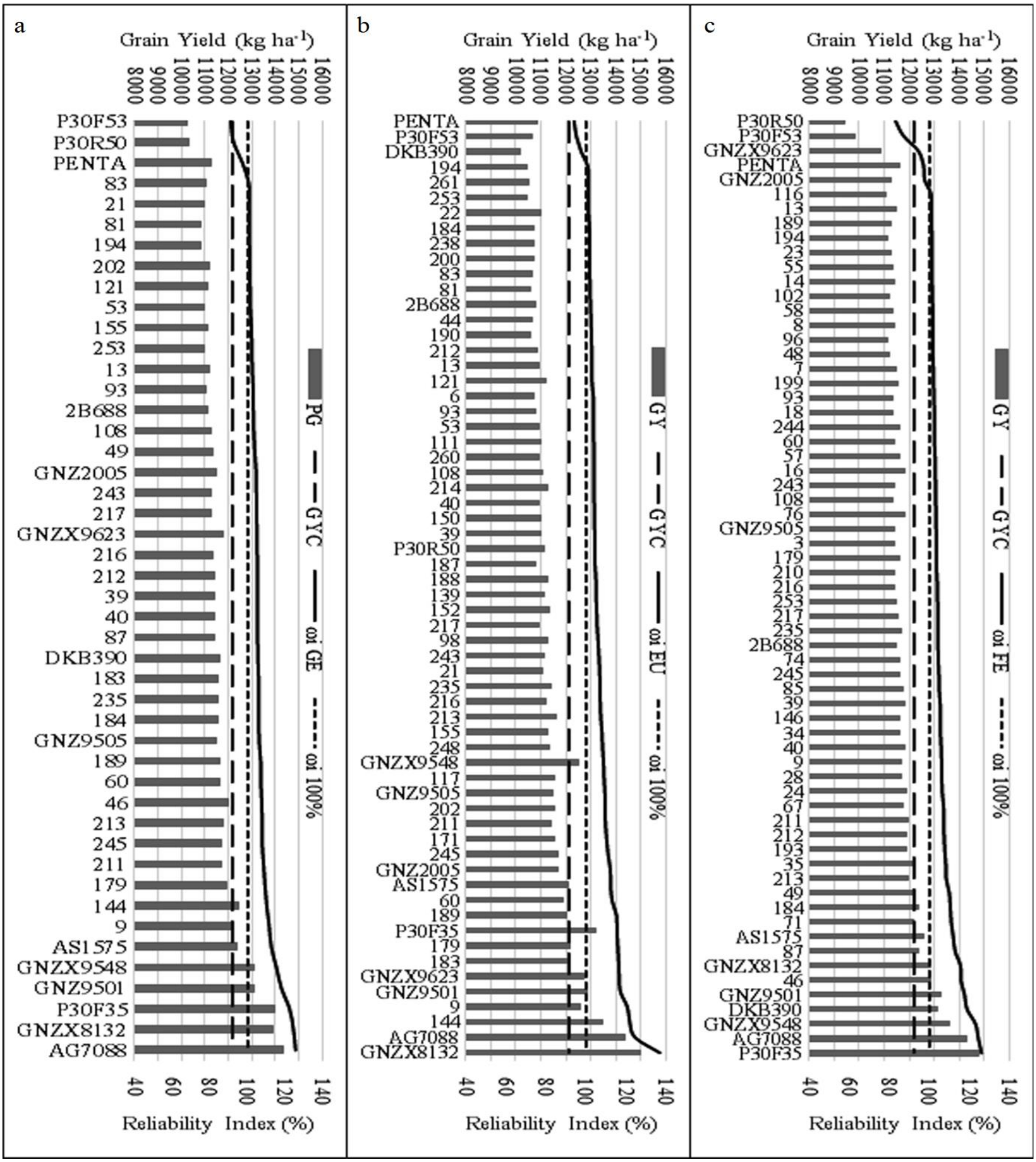
Among the genotypes presenting stability in general environment, being adapted to favorable environments, we may highlight the topcrosses 9, 13, 40, 46, 49, 60, 87, 93, 108, 121, 179, 184, 189, 194, 211, 212, 213, 216, 217, 235, 243, 245, and 253, besides the checks 2B688, AG7088, AS1575, DKB390, GNZ9501, GNZ9505, GNZX8132, GNZX9548, and P30F35, with a ωi index above 100%. On the other hand, considering general environment stability and unfavorable environments together, the topcrosses 9, 13, 21, 39, 40, 53, 60, 81, 83, 93, 108, 121, 144, 155, 179, 183, 184, 189, 194, 202, 211, 212, 213, 216, 217, 235, 243, 245, and 253 stood out, besides the checks 2B688, AG7088, AS1575, GNZ2005, GNZ9501, GNZ9505, GNZX8132, GNZX9548, GNZX9623, and P30F35 (Figure 2).

Considering the joint analysis of general adaptation, unfavorable and favorable environments, 13% of the topcrosses excelled (9, 13, 39, 40, 60, 93, 108, 179, 184, 189, 194, 211, 212, 213, 216, 217, 235, 243, 245, and 253), as well as the checks 2B688, AG7088, AS1575, GNZ9501, GNZ9505, GNZX8132, GNZX9548, with P3F35 showing a ωi index above 100% (Figure 2).

These results show the productive potential and stability of the evaluated genotypes, indicating the existence of partly inbred lines within the population, which can be used in crosses for generating new hybrids. Our outcomes corroborate the results of Guedes et al. (2011), who reported the possibility of finding promising lines derived from commercial hybrids.

Thus, the outstanding genotypes proved to have stability, besides being responsive in favorable and unfavorable environments. Hence, the respective partly inbred lines could contribute to inbreeding process, for further assessment of hybrid combinations in more years and locations. Moreover, these lines demonstrated the potential to generate stable and productive hybrids. Some genotypes stood out over the others, showing greater stability and grain yields in the evaluated environments. Additionally, these genotypes were allocated amongst the best genotypes in more than one environment.

Figure 2. Means of Grain Yield (GY), grain yield of checks (GYC), and reliability index of Annicchiarico (ω_i) for general adaptation (A), favorable environments (B), and unfavorable environments (C) of topcross hybrids with ω_i superior to 100% and 14 checks assessed in the environments of Guarapuava-PR, Candói-PR, Guarda-Mor-MG, and Paracatu-MG, UNICENTRO, 2016.



Finally, we must highlight the topcrosses 87 (Candói and Paracatu – ωi general = 105.60%), 144 (Guarapuava, Guarda-Mor, and Paracatu – ωi general = 110.51%), 179 (Guarapuava and Paracatu – ωi general = 109.52%), 211 (Guarapuava and Paracatu – ωi general = 108.86%), so they should be recommended for cultivation where they succeeded, when reaching homozygosis. The recommendation of genotypes based on the Annicchiarico stability analysis, modified by Schmildt and Cruz (2005), is reliable and has similar results to other methods (BARROS et al., 2012; SCHMILDT; CRUZ, 2005; SCHMILDT et al., 2011). Nevertheless, there are still few studies in the recent literature on adaptability and stability of maize topcrosses.

Conclusions

The commercial maize single-cross hybrid, Penta, is a feasible genotype for the development of promising lines of new competitive hybrids.

The topcrosses 87, 144, 179, and 211 presented stability for grain yield in the assessed environments, being able to be used as hybrids after the lines reach homozygosis. Furthermore, partly inbred lines from the topcrosses 13, 39, 40, 60, 93, 108, 179, 184, 189, 194, 211, 212, 213, 216, 217, 235, 243, 245, and 253 must remain in inbreeding process.

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