

Combining ability of tropical maize cultivars in organic and conventional production systems

Capacidade de combinação de milho tropical em sistemas de produção orgânico e convencional

Lucimar Rodrigues de Oliveira^I Glauco Vieira Miranda^{II} Rodrigo Oliveira DeLima^I
Leandro Vagno de Souza^{II} João Carlos Cardoso Galvão^I Izabel Cristina dos Santos^{III}

ABSTRACT

The objectives were to identify maize germplasm for the organic production system and to compare the genetic effects of the grain yield of maize cultivars in organic and conventional production systems. Diallel crosses were made between six maize cultivars and the hybrid combinations were evaluated in conventional and organic production systems. The hybrid combinations produced different grain yields in the two production systems. The interaction between general combining ability and production systems was significant for grain yield, ear height and number of ears. This indicates that the additive genetic effects differ in organic and conventional production systems. The specific combining abilities (SCA) were significant for grain yield and plant height, indicating a significant difference between the non-additive effects. However, the SCA x production systems interactions were not significant for those traits. It was concluded that for the development of maize cultivars for the organic production system, selection must be made in the specific environment for the expression of favorable alleles that confer advantages for adapting to this system; the general combining ability of genitors is different for the two production systems, but the specific combining ability isn't different in organic and conventional systems.

Key words: *Zea mays*, breeding, selection, diallel, genotype x environment interaction

RESUMO

Os objetivos foram identificar germoplasma de milho para o sistema de produção orgânica e comparar os efeitos genéticos da produtividade de grãos de cultivares de milho em sistemas de produção orgânico e convencional. Para

isso, cruzamentos dialélicos foram realizados entre seis cultivares de milho e as combinações híbridas avaliadas em sistemas de produção orgânico e convencional. Os híbridos apresentaram diferentes produtividades de grãos nos dois sistemas de produção. A interação entre a capacidade geral de combinação (CGC) e os sistemas de produção (SP) foi significativa para produtividade de grãos, altura de espiga e número de espigas. Isso indica que os efeitos genéticos aditivos diferem nos sistemas de produção orgânica e convencional. A capacidade de combinação específica (CEC) foi significativa para produtividade de grãos e altura de plantas o que indica a diferença significativa entre os efeitos não aditivos dos genitores. Entretanto, a interação CEC x SP foi não significativa para esses caracteres. Conclui-se que, para o desenvolvimento de cultivares de milho para sistema de produção orgânico, a seleção deve ser feita no ambiente específico para a expressão dos alelos favoráveis que conferem vantagens para adaptar a este sistema; a capacidade geral de combinação dos genitores é diferente nos dois sistemas de produção, mas a capacidade específica de combinação é semelhante nos sistemas orgânico e convencional.

Palavras-chave: *Zea mays*, melhoramento, seleção, dialelo, interação genótipos x ambientes.

INTRODUCTION

The area devoted to certified organic production worldwide is about 31 million hectares in 120 countries, of which Brazil is in sixth position. The growth in sales of organic products in the world is

^IDepartamento de Fitotecnia, Universidade Federal de Viçosa (UFV), 36570-000, Viçosa, MG, Brasil. E-mail: glaucovmiranda@ufv.br.
^{II}Autor para correspondência.

^{III}Dow Agrosociences Indústria Ltda, Ribeirão Preto, SP, Brasil.

^{III}Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), São João Del Rey, MG, Brasil.

currently about 7 to 9% per annum and the most important markets are in Europe and the United States (WILLER & YUSSEF, 2009). In Europe, agriculture is oriented to organic production systems that are sustainable and have low inputs (LAMMERTS VAN BUEREN et al., 2008).

Differences of maize cultivar performances are very common in tropical regions and production systems with low or high input (SILVA et al., 2003; MIRANDA et al., 2009; SOUZA et al., 2010). Those cultivars that were developed for use with high inputs to achieve higher yields in conventional production systems are not suited to the organic production system (LAMMERTS VAN BUEREN & STRUIK, 2004). Similarly, the germplasm selected under favorable edaphoclimatic conditions is not suitable for use without restriction in abiotic stress environments (CECCARELLI, 1996) because, in general, part of the alleles that control productivity under abiotic stress differ from those in optimal environments (ATLIN & FREY, 1989). Specific plant breeding for the organic system is urgently needed, including the development of cultivars with specific traits such as an extensive and deep root system, in order to increase the ability of plants to compete in interspecific competition with weeds and to stabilize production (LAMMERTS VAN BUEREN et al., 2008).

Plant breeding in the organic production system has to take into account important aspects that can be improved effectively, such as competitiveness with weeds, nutrient use and absorption efficiency (WOLFE et al., 2008), production stability, adaptability and disease resistance (LAMMERTS VAN BUEREN et al., 2002). Some characteristics of plant growth like disease are more important for organic production systems than conventional systems, with more negative effects on productivity and other traits when pesticides are not applied (KRISTENSEN & ERICSON, 2008). The differences between organic and conventional systems for cereal are large enough to justify the development of plant breeding programs that are specific for the organic production system (WOLFE et al., 2008).

In plant breeding programs, diallel crosses are widely used in the selection of parents, providing information on the predominant type of gene action and enabling estimation of the heterosis and the general and specific combining ability for genotypes, therefore helping the breeder to choose the selection method (CHAVES et al., 2008; SOUZA et al., 2008; FRITSCHENETO et al., 2010a). The methods most commonly used for diallel analysis in maize are those described by GRIFFING (1956). The development of superior hybrids depends on the combination ability of the genitors, and the ability to obtain hybrids that express a high

degree of heterosis is greater in crosses between lines that are not related. The commercial hybrids are good source to make populations to extract lines because the combining ability of hybrids is maintained for other generations (SOUZA SORBINHO et al., 2002).

The objectives of this study were to identify maize germplasm for the organic production system and compare the genetic effects of the grain yield of maize cultivars in organic and conventional production systems.

MATERIALS AND METHODS

Fifteen hybrid combinations were obtained from a diallel cross with six cultivars ('AG 1051', 'AL 25', 'AL 30', 'AG 4051', 'D 170' and 'D 270'). The 'AL 25' and 'AL 30' are open pollinated varieties, the 'AG 1051' is two-way hybrid, 'D 170' and 'AG 4051' are three-way hybrids and 'D 270' is a simple hybrid. All cultivars have dent kernel and were adequate to be consumed in green ears. The 'AG 1051', 'D 270' and 'AL 25' were chosen because of their superior performance in organic environments (SANTOS et al., 2005). The experiments (organic production system and conventional production system) were evaluated at "Diogo Alves de Mello" Experimental Station in Viçosa, Minas Gerais (latitude 20° 45' 20" S, longitude 42° 52' 40" W, elevation 640masl).

The experimental design was a randomized block design with three replicates. The experimental plot consisted of two rows, each five meters long. The spacing between rows was 0.9m, with 0.20m between plants, and a final stand density of 55000 plants ha⁻¹. The genotypes were the 15 hybrid combinations obtained from the diallel and six controls ('D 170', 'D 270', 'AL 25', 'BR 201', 'BR 106' and 'UFVM 100'). The traits that were measured were the grain yield (GY, kg ha⁻¹ corrected to 13% moisture), plant height (PH, cm) and ear height (EH, cm).

In the conventional system, fertilizer was applied as a 400kg ha⁻¹ formulation of 8-28-16 (N P K) at sowing with a further 60 kg ha⁻¹ of nitrogen in the form of ammonium sulfate split between the four-leaf and the eight-leaf stage of development. The chemistry traits of soil carried out in the experiment at the organic production system were pH (H₂O), 5.9; 10.9mg kg⁻¹ of P and 156mg kg⁻¹ of K using Mehlich⁻¹ extractable, 3.3cmol_c kg⁻¹ of Ca and 1.0cmol_c kg⁻¹ of Mg, 0.00cmol_c of Al³⁺, 4.71cmol_c of H+Al.

The organic system used an organic fertilizer source distributed in the furrows, in amounts equivalent to 40m³ ha⁻¹. The area used in this experiment has been cultivated in this way since 2002. The organic source used like fertilization was obtained by cattle

manure and crop residues. The nutrients availability in the organic compound were 0.7dag kg⁻¹, 2.8dag kg⁻¹ of K, 1.0dag kg⁻¹ of Ca, 0.4dag kg⁻¹ of Mg and 3.2dag kg⁻¹ of nitrogen. The chemistry traits of soil carried out in the conventional production system experiment were pH (H₂O), 5.5; 5.7mg kg⁻¹ of P and 71mg kg⁻¹ of K using Mehlich⁻¹ extractable, 2.5cmol_c kg⁻¹ of Ca and 1.02cmol_c kg⁻¹ of Mg, 0.00cmol_c of Al³⁺, 3.96cmol_c of H+Al, 20.4mg kg⁻¹ of Zn, 98.5mg kg⁻¹ of Fe, 80.9mg kg⁻¹ and 3.21mg kg⁻¹ of Cu.

For the combined analysis of variance and analysis of variance in each environment, the effect of blocks was considered to be random and the effect of genotypes and other factors was considered to be fixed. The methodology used to estimate the effects of general and specific combining ability was described by GRIFFING (1956) (Method 4), using only the hybrid combinations.

RESULTS AND DISCUSSION

In the combined analysis of variance, the genotypes x production systems (genotypes x PS) interaction and the hybrids combinations x production systems (HC x PS) interaction was significant only for GY, showing the difference in performance of the genotypes due to production systems variations (Table 1). The results of this study were similar to those of MURPHY et al. (2007), who evaluated 35 lines of winter wheat in organic and conventional systems at five locations over two years and found significant differences in performance for the genotypes x production systems

interaction at four of the five sites. The different response of maize genotypes in different environments is common and the genotype x environments interaction is very important for plant breeding (MIRANDA et al., 2009; FALUBA et al., 2010; FRITSCHÉ-NETO et al., 2010b). Differences in cultivar performance between organic and conventional environments were found by SILVA et al. (2007) for maize and by PRZYSTALSKI et al. (2008) for barley, wheat and winter triticale, from trials performed in Denmark, Sweden, Netherlands, France, Switzerland, UK and Germany. The controls x PS interaction were not significant for GY, PH and EH showing that the controls didn't have performance differenced due to production systems variations.

Combined diallel analysis was not significant for GCA for GY, but the GCA x PS interactions were significant, showing that in this case, the additive genetic effects were influenced by the production system and, that parent selection should be made in the specific environment (Table 2). The PH and EH showed significant effects for GCA, but the PS x GCA interaction was significant only for EH. The absence of a significant SCA x environment interaction in the diallel analysis showed that the hybrid combinations didn't have performance differenced due to production systems variations and thus the average of the SCA can be used as a parameter for selection of hybrid combinations in a specific environment. The SCA is related to the genetic distance between parents. High values, either positive or negative, indicate that the performance of certain combinations of hybrids is higher or lower than expected based on the GCA of the parents involved.

Table 1 - Mean Square of combined analysis of variance for grain yield (GY, kg ha⁻¹), plant height (PH, cm), and ear height (EH, cm) of maize hybrids combination evaluated in organic and non-organic production system.

SV	DF	-----Mean Square-----		
		GY	PH	EH
Blocks / Production system (PS)	4	6 413 913	873	463
Genotype	(20)	3 877 041 ^{ns}	768 ^{**}	659 ^{**}
Hybrid combination (HC)	14	3 488 081 ^{ns}	611 ^{**}	522 ^{**}
Control (C)	5	4 995 199 ^{ns}	622 ^{**}	488 ^{**}
HC vs Control	1	3 731 ^{**}	3 693 ^{**}	3 436 ^{**}
Production system (PS)	1	9 055 881 ^{ns}	1 5431 [*]	8 162 [*]
Genotypes x PS	(20)	2 533 458 [*]	154 ^{ns}	121 ^{ns}
HC x PS	14	2 755 176 [*]	119 ^{ns}	134 ^{ns}
Controls x PS	5	1 854 531 ^{ns}	50 ^{ns}	29 ^{ns}
(HC vs Controls) x PS	1	2 824 039 ^{ns}	1 153 ^{**}	398 [*]
Error	80	1 339 241	146	88
CV (%)		20	5	8

^{ns}: not significant at P>0.05 by F test; *, ** significant at P<0.05 and P< 0.01, respectively, by F test

Table 2 - Mean square of individual and combined diallel analysis for grain yield (GY, kg ha⁻¹), plant height (PH, cm), ear height (EH, cm) and number of ears (NE) of maize hybrid combinations evaluated in organic (OS) and conventional production system (CS).

SV	DF	-----Grain yield-----		-----Plant height-----		-----Ear height-----	
		OS	CS	OS	CS	OS	CS
Blocks	2	1 167 160	1 156 220	1 523	223	696	230
Genotype	(20)	3 859 423*	2 521 076**	623**	299*	488**	292**
HC / PS	14	3 097 478*	3 145 779**	478**	253 ^{ns}	409**	247**
GCA	5	5 923 344**	5 963 440*	838**	281 ^{ns}	801**	193 ^{ns}
SCA	9	1 526 558 ^{ns}	1 580 722 ^{ns}	278 ^{ns}	236 ^{ns}	191 ^{ns}	277*
Control	5	5 459 922*	1 389 808 ^{ns}	255 ^{ns}	417*	189 ^{ns}	328**
HC vs Controls	1	6 524 161 ^{ns}	31 568 ^{ns}	4 487**	359 ^{ns}	3087**	747**
Error	40	1 339 241	1 339 241	146	146	88	88
Genotypes	(20)	3 877 041 ^{ns}		768**		659**	
GCA	5	4 864 665 ^{ns}		1 001*		839*	
SCA	9	2 723 157**		395*		346 ^{ns}	
PS	1	9 055 881 ^{ns}		15 431*		8 162*	
GCA x PS	5	7 022 119*		118 ^{ns}		156*	
SCA x PS	9	384 123 ^{ns}		120 ^{ns}		122 ^{ns}	
Error	80	1 339 241		146		88	

^{ns}: not significant at P>0.05 by F test; *,** significant at P<0.05 and P<0.01, respectively, by F test.

In the organic system, the genotype and hybrid combination effects were significant for all traits (Table 2). The controls produced statistically significant differences in grain yield (GY). The non-significance of HC vs controls for GY indicated similar behavior between HC and controls in organic and conventional production system. The performance of the controls and HCs didn't differ significantly in terms of GY. In terms of PH and EH, the differences were significant, showing the different performance of the controls and the HCs.

The importance of general combining ability (GCA) for the characteristics GY, PH and EH indicated the presence of favorable additive alleles specific to the organic production system in some of the parents and thus the selection of parents for the organic system can be made on the basis of these characteristics (Table 2). The significance and, or predominance of one type of genetic effect depends on the population involved in the diallel, so the results will be specific to the parents evaluated.

In the conventional production system, the genotypes were significant for all traits (Table 2). The effect of HC was statistically significant for GY and EH, which indicates the different performance between cultivars. Therefore, the influence of genotypes on GY is due to the differences between the HC and not among the controls. The difference between HC and controls was statistically significant only for EH. The lack of significance for other characteristics shows that the

performance of the controls and HCs in this environment was similar. This production system, the GCA effect was significant only for GY, which indicates the presence of favorable additive alleles specific to the conventional environment, whereas the SCA effect was significant only for EH. The additive effects were of greatest importance for GY, while for EH non-additive effects were the most important (Table 2).

For GY, the HC average was approximately 10% higher in the organic than in the conventional system for all traits. The HC average was higher than the control average in the two production systems, demonstrating the commercial viability of the HCs. This shows that the HC have the potential for organic system production.

In the organic production system, the cultivars 'AG 1051' and 'AL 25' were a parent of five and four hybrid combinations that yielded above average, respectively (Table 3). In the conventional production system, the most productive cultivars were the HCs in which 'AG 4051', 'D 270' or 'AG 1051' was one of the parents. In the organic production system, the most productive control was the cultivar 'AG 1051' (8 114kg ha⁻¹) whereas in the conventional production system the most productive was 'AL 25' (6202kg ha⁻¹).

The HC productivity varied between 19% ('D 270' x 'AG 4051') and 76% ('AG 1051' x 'AL 25') between organic and conventional production, which explains the importance of the HC x PS interaction and shows that HC should be selected for each specific

Table 3 - Means of grain yield (GY, kg ha⁻¹) of hybrid combination and controls in the organic and conventional production system, differences of GY between systems (%), average estimate of specific combining ability (SCA) and estimates of general combining ability effects of maize cultivars for grain yield in organic and conventional production systems.

Hybrid Combination	Organic System	Conventional System	%	SCA
'AG 1051' x 'D 170'	7 621	6 030	26	1 017
'AG 1051' x 'D 270'	5 544	6 352	-13	-193
'AG 1051' x 'AL 25'	7 974	4 532	76	-284
'AG 1051' x 'AL 30'	6 354	4 728	34	-453
'AG 1051' x 'AG 4051'	6 510	6 868	-5	-86
'D 170' x 'D 270'	4 001	4 068	-1	-986
'D 170' x 'AL 25'	6 615	4 764	39	272
'D 170' x 'AL 30'	5 376	4 045	33	-162
'D 170 x 'AG 4051'	5 185	5 843	-11	-141
D 270' x 'AL 25'	7 043	5 683	24	613
'D 270' x 'AL 30'	5 949	6 047	-1	790
'D 270' x 'AG 4051'	5 163	6 367	-19	-224
'AL 25' x 'AL 30'	6 275	3 702	69	-614
'AL 25' x 'AG 4051'	6 632	6 162	7	12
'AL 30' x 'AG 4051'	6 201	6 364	-2	440
'AL 25'	5 537	6 202	-11	-
'D 170'	5 007	5 507	-9	-
'AG 1051'	8 114	5 952	36	-
'BR 106'	4 645	4 406	5	-
'BR 201'	4 579	5 465	-16	-
'UFVM 100'	4 823	4 795	0.6	-
HC Mean	6 163	5 437	-	-
Controls Mean	5 450	5 388	-	-
General Mean	5 959	5 423	-	-
-----General combining ability-----				
'AG 1051'	769	331	-	-
'D 170'	-503	-609	-	-
'D 270'	-778	333	-	-
'Al 25'	913	-585	-	-
'Al 30'	-164	-575	-	-
'AG 4051'	-280	1 104	-	-

environment (Table 3). For controls, despite the lack of a significant control x PS interaction, there was a change of -16% ('BR 201') to 36% ('AG 1051'). PRZYSTALSKI et al. (2008) assessed the trials of various crops such as barley, wheat and triticale in the spring systems of conventional and organic production in Denmark, Sweden, Holland, Belgium, France, Switzerland, UK and Germany. They found high correlations between the systems for most characteristics in all countries. However, there was moderate coincidence between cultivar ranks.

Parents who had high positive values of GCA were 'AG 1051' and 'AL 25' in the organic

production system and 'AG 4051', 'D 270' and 'AG 1051' in the conventional system (Table 3). High values of GCA (positive or negative) indicate parents that are better or worse than the others used in the diallel while lower estimates of GCA (positive or negative) indicate those do not differ much from the average of all crossings in the diallel (CRUZ et al., 2004).

Of the four most productive hybrid combinations in the organic production system, one of the parents was 'AG 1051' or 'AL 25', these being the parents with the highest GCA estimates (Table 3). Among the combinations that produced an average of

more than 6000kg ha⁻¹ in the organic environment, with the exception of 'AL 30' x 'AG 4051', at least one parent had a high positive GCA. In the conventional production system, the most productive HC (over 5500kg ha⁻¹) had 'D 270', 'AG 1051' or 'AG 4051' as a parent cultivar (Table 3). Although this indicates that at least one parent with high GCA was used in the synthesis of hybrids, the hybrid combination of 'AL 30' x 'AG 4051' was ranked the most productive in the organic production system, although their parents had a negative GCA. This fact can be explained by the high estimate of SCA, which indicates the existence of complementarity between the parents and the manifestation of heterosis in the offspring.

BURGER et al. (2008) conducted experiments to determine the genetic parameters of maize that could be used to identify the best strategies for improvement and prospects for selection in organic production systems. The average productivity in the organic system was 16% lower than in the conventional system. The phenotypic correlation between production systems for GY was low ($r_p=0.21$). Based on the performance of HC there is no evidence of any adjustment in the two systems (Table 3). A small proportion of the hybrids showed superior performance in both production systems.

CONCLUSION

For the development of maize cultivars in the organic system, selection must be made in the target environment for the expression of favorable alleles that confer advantages for adapting to this system, allowing the selection of superior parents.

For the germoplasm maize evaluated, the general combining ability of parents is different in the two systems and there is a need to select and develop varieties specifically for organic or conventional production systems. The specific combining ability isn't different in organic and conventional production systems.

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