Heterosis and its components in crosses among high quality protein maize populations

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ABSTRACT

The objective of the present study was to investigate heterosis in high quality protein maize populations of distinct grain type groups. Agronomic traits and reaction to some leaf diseases of 19 yellow grain populations were assessed in a partial diallel grown in four environments. For grain yield trait, only variety effects and average heterosis were significant, indicating that the best intervarietal hybrids can be predicted using the means of the parental populations. The BR 473 and CMS 52 flint populations, the CMS 474 and ZQP 103 dent populations are recommended for an inter-group reciprocal recurrent selection program. In a decreasing order of preference, the dent type CMS 474, ZQP 103 and ZQP 101 populations and the flint type BR 473, CMS 455C, CMS 453, CMS 52, CMS 455 and CMS 458 are recommended to form composites.

KEY WORDS: Maize, QPM, *zea mays*, diallel, heterosis.

INTRODUCTION

The maize is a vital food source in many areas of the developing world, particularly in poor rural communities. Cropping in poor countries spreads rapidly because of maize robustness and its high adaptability to a wide range of environments. It is the staple food for the people in many Latin American countries. In industrialized countries, it is mainly used as animal food. The protein content in maize grains is about 9.5% and the 42 million tons of maize protein approximately produced account for 15% of the world protein production (National Research Council, 1988).

However, zein - the main maize grain protein - is poor in lysine and triptophan and presents low digestibility. Consequently, the cereal has lower protein quality for monogastric animal nutrition compared to other sources. The Opaque 2 (o_2) gene increases significantly the lysine and triptophan contents in the endosperm (Mertz et al., 1964), but expresses negative pleiotropic effects on the grain quality, such as lower density, susceptibility to pests and diseases and a floury appearance (Vasal, 1994).

The International Maize and Wheat Improvement Center (CIMMYT) sought to solve these problems by introducing modifier genes for denser and more vitreous endosperm. The improved populations, which were called QPM (Quality Protein Maize), presented protein with a greater biological value, as well as yield and agronomic characteristics which were closer to normal cultivars. The biological value of the common maize protein is equivalent to approximately 40% of the biological value of milk protein, while for QPM maize this value is 90% (National Research Council, 1988).

In Brazil, the QPM breeding program begun in the National Center for Maize and Sorghum Research of Embrapa with the introduction of 23 populations in 1984 (Magnavaca et al., 1988). Breeding these populations to obtain cultivars that are more adapted to the Brazilian conditions resulted in the release of commercial cultivars with white and yellow grains, and of the BR 2121 double hybrid type with yellow grains (Guimarães et al., 1997). In diallel crosses, low heterosis among the populations bred by Embrapa was observed (Guimarães et al., 1997).

Vasal (1986) reported that heterosis exploitation in intervarietal crosses of QPM maize populations should be coupled with population breeding to allow the synthesis of a series of new hybrids at each cycle. An elite fraction represented by the recombination of few superior elite families would allow uniformity increase, better hybrid performance, and also allow the selection of those families with good endosperm modifier stability, good quality protein and few ear health problems.

Reports on heterosis in high quality protein maize populations found in the international and Brazilian literature show that assessments have been carried out using few parents, in general. These results did not suggest the existence of divergent groups involving the populations (Vasal et al., 1993a, 1993b; Parentoni et al., 1991; Guimarães et al., 1992, 1994). The present study had the objective of assessing heterosis in populations stemming from divergent groups classified according to their grain type. A comprehensive sampling of the high quality protein populations with yellow grains and vitreous endosperm available in Brazil was carried out.

MATERIAL AND METHODS

Nineteen QPM populations with yellow grains from the germplasm bank of Embrapa - Maize and Sorghum (CMS populations) and Empresa Brasileira de Sementes Ltda (EBS) (ZQP populations) were used in this study. These populations were divided according to their grain type to establish different heterosis groups. Group I involved six dent grain populations and group II involved 13 flint populations (Table 1).

The diallel crosses were carried out between the population groups in the winter season of 1997 at the EBS experimental station located in Rio Verde-GO. Populations from group 1 were used as males in crosses with those from group 2. Only the crosses between the CMS 456 population and the CMS 453, CMS 455, CMS 455C and CMS 458 populations were not obtained.

The parental populations and F1 hybrids were sowed in the 1997/98 growing season in experimental areas at EBS in Rio Verde-GO and Cravinhos-SP and at the Agronomy School at the Federal University of Goiás (EA-UFG), in Goiânia-GO. The materials were also sown on January 22, 1998 ("safrinha" growing season) in an experimental area at Embrapa - Maize and Sorghum in Sete Lagoas-MG.

The 19 parental populations, 74 F1 hybrids and two controls were distributed in four randomized complete block design experiments with four replications. The Z 8452 and BR 2121 hybrids were used as controls in all experiments. The Z 8452 control is an elite single cross hybrid from EBS with yellow grains and normal endosperm, which is recommended for high technological level cropping in tropical and subtropical zones in soils with medium to high fertility. BR 2121 is a double cross hybrid with yellow grains with QPM endosperm synthesized by Embrapa - Maize and Sorghum.

Each experimental plot was formed by a single five-meter row with five plants per meter. Spacing between rows was 0.8 m in Rio Verde-GO and Cravinhos-SP and 0.9 m in Goiânia and Sete Lagoas. In the latter, irrigation was used only when absolutely necessary.

The following traits were assessed: (a) plant height (PH); (b) ear height (EH); (c) ear height/plant height ratio (E/P); (d) percentage of broken plants (BP); (e) percentage of lodged plants (LP); (f) days to male flowering (MF); (g) days to female flowering (FF); (h) ears per plant index (EI); (i) percentage of diseased ears (DE); (j) leaf diseases caused by the pathogens *Exserohilum turcicum* (Et), *Puccinia polysora* (Pp), *Physopella zeae* (Pz) and *Phaesophaeria maydis* (Pm) evaluated according to the assessment scale presented in the Agroceres Health Guide in 1996; (k) percentage

Table 1. Yellow grain QPM populations grouped according to grain type.

Group 1 - dent		Group 2 – flint	
Populations	Origin	Populations	Origin
CMS 456	Pool 26	CMS 52	Yellow Flint Synthetic
CMS 466	Pool 34	CMS 453	Pop. 65
CMS 467	Amarillo del Bajio	CMS 455	Pool 25
CMS 474	25% BR 105 + 75% CMS 456	CMS 455 C	75% CMS 455 + 25% CMS 14C
ZQP 101	Pop. 66	CMS 458	Amarillo Cristalino
ZQP 103	Pop. 66	CMS 463	Pop. 69
		CMS 465	Pool 33
		CMS 468	Amarillo Subtropical
		CMS 470	Obregon 7941
		CMS 471	Across 7941
		CMS 472	San Jeronimo
		BR 473	Sintetic (10 lines)
		ZQP 102	Pop. 69

of plants affected by Corn Stunt complex (CS); and grain yield (GY).

The assessed traits varied according to the experiment location: Goiânia, PH, EH, E/P, BP, LP, EI, Et, Pp, Pz, Pm, CS and GY; Rio Verde, PH, EH, E/P, BP, LP, MF, FF, EI and GY; Cravinhos, PH, EH, E/P, BP, LP and GY; Sete Lagoas, PH, EH, E/P, BP, LP, EI, DE and GY.

Grain yield data were adjusted to the ideal 25 plants per plot stand by covariance analysis whenever the correction resulted in a decrease ≥ 10% in the residual mean square.

The partial diallel model adapted by Miranda Filho and Geraldi (1984) from the complete diallel of Gardner and Eberhart (1966) was used for the intergroup analysis. The adapted model is

$$Y_{ij} = \mu + \alpha d + \frac{1}{2}(v_i + v_j) + \theta(\bar{h} + h_i + h_j + s_{ij}) + \bar{e}_{ij}$$

Where:

Y_{ij}: mean of the cross between the ith variety of group 1 and the jth variety of group 2; $\theta = 1$ and $\alpha = 0$ for the crosses; for the parental varieties Y_{ij} is substituted by Y_{ii} or Y_{jj} for varieties of group 1 or 2, respectively; i = 1, 2, …, I; and j = 1′, 2′, …, J. For Y_{ii}, $\alpha = 1$ and $\theta = 0$ and for Y_{jj}, $\alpha = -1$ and $\theta = 0$;

d: half the difference between the means of the two variety groups ;

μ : average of the means of the two variety groups;

v_i and v_j: effects of the varieties from groups 1 and 2, respectively;

$\bar{h}$: average heterosis of all crosses;

h_i and h_j: varietal heterosis effects relative to groups 1 and 2, respectively;

s_{ij}: specific heterosis of the cross between the ith variety of group 1 and jth variety of group 2;

$\bar{e}_{ij}$: average experimental error associated to the hybrid or parent means.

The least squares procedure was applied to the normal equations $\boldsymbol{X'X\beta = X'Y}$, derived from the linear model $\boldsymbol{Y = X\beta + \varepsilon}$ to estimate the model effects and their respective sum of squares. $\boldsymbol{Y}$ is the vector of the observed means, $\boldsymbol{X}$ is the information matrix of coefficient according to the adopted model, $\boldsymbol{\beta}$ is the vector of parameters to be estimated and $\boldsymbol{\varepsilon}$ is the experimental error vector. The following restrictions were adopted to solve the system of equations: $\sum \hat{v}_i = \sum \hat{v}_j = \sum \hat{h}_i = \sum \hat{h}_j = 0$. The general combining ability of each population was calculated using the expression:

$\hat{g}_i = \frac{1}{2}\hat{v}_i + \hat{h}_i$ or $\hat{g}_j = \frac{1}{2}\hat{v}_j + \hat{h}_j$, where, g_i and g_j are the effects of general combining ability of the ith population in group 1 and jth population in group 2, respectively. The joint analysis of the diallel tables for the four experiments was carried out according to Miranda Filho and Vencovsky (1995).

RESULTS AND DISCUSSION

A breeding strategy for high protein quality germplasm cannot be carried out without the help of grain and protein quality analyses (Vasal, 1994). Therefore, the results obtained here, which refer to agronomic performance, can only be used as an initial reference for breeding work.

Table 2 shows the joint analyses of variance according to the adopted partial diallel model. Only traits shown significance to any effect are presented. The effects of varieties, varieties within dent groups, varieties within flint group and average heterosis were significant for grain yield. This indicated the presence of significant variability among the evaluated parental populations in the two groups. In the within-location analyses, the variety effects were not significant only in Cravinhos, which was also the only location where the variety heterosis effects were significant (data not shown). Therefore, one can say that the average heterosis is the most important heterosis component in the studied material.

According to the interpretation given by Vencovsky (1970) to the complete model of Gardner and Eberhart (1966), we can suggest that average heterosis depends on whether there are effects of dominance and differences in gene frequencies among the considered population groups. Similarly, the varietal heterosis depends on whether there are differences among the gene frequencies of a variety in relation to the mean gene frequency of the parents in the same group. Thus, the significance of the average heterosis effect indicates divergence among the gene frequencies of the dent and flint population groups for the loci displaying dominance. A recurrent selection program will lead to an increase in the heterosis among these populations if there is an increase in gene frequency divergence. However, if the increase is in the same direction and with the same magnitude in the two populations, the heterosis will remain unaltered, as stated by Hallauer and Miranda Filho (1981). The non-significance of the varietal heterosis effect suggests there are no important differences among populations of same grain types, since it is a consequence of similar gene frequency in loci expressing some dominance in these populations. We can conclude from these results that grouping the varieties according to grain type was effective to form heterosis groups among the studied populations, and that, within groups, there was a certain homogeneity of gene frequencies of loci displaying some dominance. These results indicate, therefore, that the hybrid performance is related to the mean of the parental populations. Populations with a higher performance in each group, when combined, tend to generate superior intervarietal hybrids, since the manifestation of heterosis is similar for the different hybrids.

We observed that the average heterosis values were similar to those found in this study in the combining ability studies carried out with high protein populations from CIMMYT, and that specific heterosis is of little importance (Parentoni et al, 1991; Guimarães et al, 1992, 1994; Vasal et al, 1993a, 1993b; Pixley and Bjarnason, 1993). According to Pixley and Bjarnason (1993), the reasons for the low CEC importance are the non-partition of the lines in heterotic groups during their development and the lack of concern for heterosis during the QPM line development in CIMMYT.

The significant interaction of the variety, the variety within the dent group and grain yield average heterosis effects with locations suggest that germplasm adaptation during the breeding of the studied germplasm should be carefully studied. This is not surprising because the regions involved are reasonably far apart and show different environmental conditions. In Sete Lagoas, the location effect is confused with the season effect, since it involves cropping maize in the off-season ("safrinha"), while in all other locations cropping was in the normal season. The environment effects were less pronounced in the flint varieties compared to the dent group under the conditions studied, as can be inferred from the significance of the variety x environment interactions. A significant interaction of the combining ability for grain yield in high quality protein germplasm has also been reported by Vasal et al. (1993a) and Pixley and Bjarnason (1993).

Table 3 shows estimates of the effects, which were significant in the diallel analysis. For grain yield, the largest variety effect estimates were 1.015 t/ha and 0.856 t/ha for the CMS 474 and ZQP 101 populations, respectively, in the dent group. This suggests that these populations have a better frequency of favorable

Table 2. Joint analysis of variance for grain yield (GY – t/ha), plant height (PH – m), ear height (EH – m), ear height/plant height ratio (E/P), ears per plant index (EI), days to female flowering (FF), and days to male flowering (MF) in yellow grain maize populations and hybrids with high quality protein.

Source of Variation	d. f.[1/]	M. S.						
		GY	PH	EH	E/P	EI	FF	MF
Varieties	18	2.444[2/]	0.0380[2/]	0.0318[2/]	0.0014	0.0078	5.459[2/]	7.585[2/]
Group 1	5	4.672[2/]	0.0519[2/]	0.0540[2/]	0.0025	0.0244[3/]	9.926[2/]	14.585[2/]
Group 2	12	1.544[2/]	0.0347[2/]	0.0252[2/]	0.0010	0.0015	4.015[2/]	5.299[2/]
G1vsG2	1	2.109	0.0073	0.0000	0.0000	0.0006	0.451	0.011
Var. x Locations	18(L-1)	1.041[3/]	0.0101	0.0073	0.0015	0.0102	5.197[2/]	11.694[2/]
G1x Locations	5(L-1)	3.135[2/]	0.0301[2/]	0.0168[3/]	0.0036[2/]	0.0330[3/]	12.494[2/]	29.301[2/]
G2 x Locations	12(L-1)	0.170	0.0020	0.0038	0.0007	0.0015	2.571[2/]	5.307[2/]
G1vsG2xLocations	(L-1)	1.028	0.0077	0.0018	0.0007	0.0016	0.220	0.296
Heterosis	74							
Average Het.	1	4.514[2/]	0.0096	0.0016	0.0003	0.0248	0.002	0.145
Het. Group 1	5	0.203	0.0034	0.0009	0.0003	0.0044	0.275	0.482
Het. Group 2	12	0.117	0.0037	0.0030	0.0002	0.0009	1.062	0.926
Specific Het.	56	0.060	0.0015	0.0013	0.0002	0.0009	0.269	0.374
Av. Het.x locations	(L-1)	1.502[3/]	0.1071	0.0471[2/]	0.0096[2/]	0.0088	12.648[2/]	26.890[2/]
Het. G1 x locations	5(L-1)	1.153[3/]	0.0141	0.0047	0.0014	0.0117	3.266[2/]	4.796[2/]
Het. G2 x locations	12(L-1)	0.100	0.0085	0.0027	0.0003	0.0008	0.323	0.674
S. Het. x locations	56(L-1)	0.158	0.0056	0.0040	0.0007	0.0062	0.536	0.782
Error/r	396(L-1)	0.572	0.0111	0.0095	0.0017	0.0086	0.610	0.879

[1/] L:4, for GY, PH, EH and E/P; L:3, for IE; L:2, for FF and MF; [2/] and [3/] - significant at the 1% and 5% levels of probability by the F test, respectively.

genes, and are suitable for intrapopulation improvement. The significance of the group x environment interaction indicates that a detailed analysis of the populations within each environment is required. In all locations, these two populations presented a positive contribution to means through the variety effect.

Among the flint populations, the largest variety effects in the joint analysis were presented by the CMS 453 (1.182 t/ha) and BR 473 (1.015 t/ha) populations. CMS 455C (0.770 t/ha), CMS 455 (0.612 t/ha) and CMS 458 (0.549 t/ha) presented intermediate values. The CMS 52 population presented a positive but small value (0.022 t/ha). These populations were promising for intrapopulation breeding due to their higher frequency of favorable alleles for yield.

The average heterosis in the joint analysis was 0.572 t/ha (11.10%). The values ranged from 0.942 t/ha (18.28%) in Rio Verde to 0.232 t/ha (3.92%) in Cravinhos.

The most promising CYMMYT introductions can be inferred from the joint assessment of the origin of the populations and from the literature, as well as from the results of this study. Population 65 (CMS 453) presented good results when evaluated using full sibs by Magnavaca et al. (1989) and also in a partial diallel among populations assessed by Guimarães et al. (1994). Similarly, population 66 (ZQP 101 and ZQP 103), mainly ZQP 101 (which is an improved version), presented good results in the present study and, along with population 65, were the highest yielding among yellow grain populations in the experiments carried out by Magnavaca et al. (1988). In the same experiment, the Pool 25 (CMS 455) and Amarillo Cristalino (CMS 458) populations showed acceptable yield levels. These two populations presented good results in the present study.

The results indicated that populations introduced from CIMMYT submitted to breeding procedures had increased their potential as base populations. This was the case of BR 473, which is a synthetic population bred at Embrapa. Similarly, the introgression of improved material for the Brazilian conditions had

Table 3. Joint analysis estimates of the effects of varieties (v), general combining ability (g), mean of varietal groups (u), deviation between varietal groups (d) and average heterosis ($\bar{h}$) for grain yield (GY – t/ha), plant height (PH – m), ear height (EH – m), ears per plant index (EI), days to female flowering (FF) and days to male flowering (MF) in yellow grain maize populations and hybrids with high quality protein.

	GY		PH		EH		EI		FF		MF	
Populations	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$
Dent												
CMS 456	0.253	-0.078	0.02	-0.02	0.01	0.01	-0.02	0.02	0.08	0.36	0.38	-0.09
CMS 466	-0.700	-0.604	-0.06	-0.06	-0.08	-0.07	-0.03	-0.04	-0.42	-0.41	-0.88	-0.75
CMS 467	-1.488	-0.617	-0.24	-0.06	-0.16	-0.06	0.01	-0.06	-2.92	-1.37	-3.13	-1.35
CMS 474	1.015	0.793	0.13	0.07	0.11	0.07	-0.06	0.04	0.83	0.65	1.13	1.04
ZQP 101	0.856	0.184	0.08	0.05	0.11	0.06	0.05	0.04	1.33	0.72	1.38	1.08
ZQP 103	0.065	0.322	0.06	0.01	0.00	0.01	0.05	-0.01	1.08	0.05	1.12	0.08
Flint												
CMS 453	1.182	0.357	0.17	0.03	0.14	0.02	-0.04	0.02	1.31	0.58	1.63	0.37
CMS 455	0.612	0.189	0.10	0.04	0.11	0.07	0.00	0.06	-0.19	0.93	0.13	1.07
CMS 455C	0.770	0.387	0.18	0.07	0.17	0.03	0.09	0.01	2.56	0.43	2.63	0.06
CMS 458	0.549	0.023	0.10	0.05	0.06	0.06	0.03	0.04	1.81	0.53	2.13	0.82
CMS 463	-0.658	-0.296	-0.07	-0.07	-0.07	-0.05	0.01	-0.03	-1.94	-1.42	-2.37	-1.47
CMS 465	-0.914	-0.373	-0.18	-0.03	-0.14	-0.01	0.00	0.01	-1.94	-0.05	-1.87	-0.43
CMS 468	-0.645	-0.558	-0.11	-0.05	-0.07	-0.04	-0.01	-0.03	-0.44	-0.46	-1.12	-0.30
CMS 470	-0.403	-0.080	-0.10	-0.03	-0.11	-0.05	-0.02	-0.03	-0.94	-0.05	-0.62	0.45
CMS 471	-0.673	-0.396	-0.18	-0.06	-0.08	-0.04	0.00	-0.02	-1.94	-0.50	-1.37	-0.39
CMS 472	-0.472	-0.272	-0.03	-0.05	-0.03	-0.05	-0.07	-0.04	-0.94	0.45	-1.37	-0.22
ZQP 102	-0.384	-0.330	0.01	-0.05	-0.04	-0.05	-0.02	-0.04	0.06	-0.38	0.38	-0.34
CMS 52	0.022	0.323	-0.12	0.01	-0.12	-0.02	0.02	-0.02	-0.19	-0.59	-1.37	-0.59
BR 473	1.015	1.026	0.21	0.13	0.17	0.11	0.01	0.08	2.81	0.54	3.13	0.92

$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$
5.151	0.168	0.572 11.10%	2.02	0.01	0.02 0.99%	1.03	0.00	0.01 0.97%	0.96	0.01	0.04 4.16%	59.08	-0.14	-0.01 -0.02%	58.21	0.00	0.09 0.15%

positive effects on the CMS 474 and CMS 455C populations. This effect was especially noticeable in the CMS 474 population, which is derived from Pool 34 population with introgression of 25% of BR 105, a normal grain population. CMS 474 presented a better performance as a base population than CMS 456, which is simply the Pool 34 introduction. Less sharply improved, CMS 455C derived from Pool 25 with 25% CMS 14C showed a better adaptation than CMS 455, which is the Pool 25 introduction. The ZQP 101 and ZQP 103 yellow grain populations were another example. The ZQP 103 population corresponded to population 66, a CIMMYT introduction, while ZQP 101 corresponds to a version of Population 66 derived from recurrent selection cycles in Brazil. In this study the ZQP 101 population was more promising than ZQP 103 as a base population.

For the traits percentage of broken or lodged plants no source of variation was significant in the analysis of variances. These traits are difficult to assess because large environmental effects cause increases in the error coefficients of variation and precludes formulating conclusions with even relative precision. The variety effect and varieties within group effects were significant for plant and ear heights. None of the heterosis components were significant for either trait. Significant interactions were observed for environment x variety within dent group and environment x average heterosis.

Few effects were significant for the traits ear height/ plant height ratio and ear index, indicating little detectable variability that could be exploited in terms of additive and dominance genetic effects or differences in gene frequencies.

The variety effects and their components were significant when the female and male flowering traits were analyzed, except for differences between varieties within groups. On the other hand, little seems to be worth exploring for breeding purposes due to the dispersion of the gene frequencies among groups and dominant gene effect, since only the interaction effects were significant for the heterosis components.

Plant height seemed to be correlated with yield. The populations with positive variety effects for yield are those that contribute to increased plant height. The variety within dent group effects were positive in the CMS 474 and ZQP 101 populations and the variety within flint group effects were positive for the BR 473, CMS 453, CMS 455, CMS 455C and CMS 458 populations.

Data on disease occurrence were collected only in Goiânia-GO. The variety effect or some of its components presented detectable differences for all leaf diseases (Table 4). However, the variety and some heterosis component effects were of low magnitude (Table 5). For resistance to *Puccinia polysora*, the smallest variety effect in the dent group was for ZQP 101, while CMS 467 presented the largest value. The CMS 458 and CMS 453 populations presented the lowest values in the flint group. Average heterosis was –13.75%, suggesting that heterosis can be explored to breed hybrids with

Table 4. Analysis of variances of resistance level to *Puccinia polysora* (Pp), *Physopella zeae* (Pz) and *Exserohilum turcicum* (Et) and percentage of plants affected by Corn Stunt (CS) in yellow grain maize populations and hybrids with high quality protein in Goiânia-GO.

Source of Variation	D.F.	MS				
		Pp	Pz	Pm	Et	CS
Varieties	18	3.9424$^{2/}$	0.1946	1.1191	0.8899	188.7815$^{2/}$
Group 1	5	10.6636$^{2/}$	0.4613$^{1/}$	1.7612$^{2/}$	1.7270$^{1/}$	207.7888$^{2/}$
Group 2	12	1.3612$^{2/}$	0.0822	0.9115$^{2/}$	0.6111$^{2/}$	164.8544$^{2/}$
G1xG2	1	1.3114	0.2101	0.3998$^{2/}$	0.0482	380.8699$^{2/}$
Heterosis	74					
Average Het.	1	3.1708$^{2/}$	0.7644$^{1/}$	0.0082	1.5961	1010.5445$^{2/}$
Het Group 1.	5	1.7833$^{1/}$	0.0888	0.4512	0.6869	87.1868
Het Group 2.	12	0.2298	0.0438	0.2365	0.2184	41.2054
Specific Het.	56	0.2140	0.0457	0.1190	0.1855	12.7951
Error	297	0.5532	0.1973	0.3426	0.5270	50.8575

$^{1/}$ and $^{2/}$ indicate significance at the 5% and 1% levels of probability by the F test, respectively.

greater resistance than the parents. For resistance to *Physopella zeae* in the dent group, the smallest variety effect was observed in CMS 467, ZQP 101 and ZQP 103 populations while the largest values were obtained in the CMS 456 population. Although significant in the analysis of variance, the average heterosis effect was low. Furthermore, the positive value indicated that, in general, heterosis was not very helpful in the search for greater resistance. For *Phaeosphaeria maydis*, the lowest variety effect was observed for the ZQP 101 and ZQP 103 populations in the dent group and for the CMS 455C, CMS 52 and BR 473 populations in the flint group. Similarly, for level of resistance to *Exserohilum turcicum*, the CMS 456 and ZQP 101 populations presented the smallest variety effects in the dent group and CMS 453 in the flint group. Hetorosis components were not significant for *P. maydis* and *E. turcicum* evaluations.

Significant variability was detected for percentage of plants affected by Corn Stunt. The sources of variation among populations, between population groups and the heterosis among groups were significant (Table 4). The non-significant variety heterosis effect suggests that the populations within a group do not differ in terms of complementation with the populations of the contrasting group. The dent populations that contributed more to the increase of resistance were CMS 474 and ZQP 101 and in flint group CMS 453, CMS 455, CMS 455C, CMS 458 and BR 473. The average heterosis value was –47.94%, indicating that exploitation of among group heterosis would lead to an increase of resistance (Table 5).

According to Miranda Filho and Chaves (1991), the high variability expected in variety composites makes them quite adequate for use as base population in breeding programs. The number of composites that can be obtained from a certain number of varieties may restrict yield prediction and detection of the most favorable ones, and this should be taken into account. Therefore, these authors studied models for yield means prediction and observed that general combining ability (GCA) can be a good parameter for the selection of the varieties to form a composite. Tables 3 and 5 show the estimated GCA values (g_i or g_j) for the studied

Table 5. Estimates of the effects of varieties (v), general combining ability (g), mean of varietal groups (m), among varietal groups deviations (d) and average heterosis ($\bar{h}$) for resistance level to *Puccinia polysora* (Pp), *Physopella zeae* (Pz) and *Exserohilum turcicum* (Et) and percentage of plants affected by Corn Stunt (CS) in Goiânia-GO.

	Pp		Pz		Pm		Et		CS	
Populations	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$	$\hat{v}$	$\hat{g}$
Dent										
CMS 456	-0.08	-0.33	0.33	0.02	-0.08	-0.34	-0.38	-0.50	-8.83	-2.48
CMS 466	0.42	0.66	0.08	0.25	0.42	-0.17	0.88	0.07	15.16	4.95
CMS 467	1.17	1.41	-0.17	-0.34	0.42	0.75	-0.12	0.79	21.77	1.37
CMS 474	-0.33	-1.15	0.08	0.13	-0.08	-0.37	-0.12	-0.01	-9.88	0.32
ZQP 101	-0.83	0.29	-0.17	-0.05	-0.33	0.15	-0.38	0.00	-11.28	-1.73
ZQP 103	-0.33	-0.88	-0.17	0.00	-0.33	-0.02	0.12	-0.34	-6.96	-2.43
Flint										
CMS 453	-1.10	-0.46	-0.10	0.09	0.10	-0.38	-0.75	-0.15	-10.51	0.60
CMS 455	-0.60	-0.71	-0.10	-0.07	-0.15	0.27	0.25	-0.15	-10.38	-3.94
CMS 455C	-0.10	-0.66	-0.10	-0.02	-0.65	-0.53	0.00	-0.40	-17.45	-3.87
CMS 458	-1.35	-0.56	-0.10	-0.02	-0.15	0.22	-0.25	-0.50	-16.41	-3.39
CMS 463	0.90	0.78	-0.35	-0.12	-0.15	0.07	0.00	0.35	12.39	1.43
CMS 465	1.15	0.28	0.40	0.09	-0.15	0.20	0.75	0.23	20.49	0.57
CMS 468	0.40	0.20	0.15	-0.08	0.10	0.07	0.75	0.56	-0.91	1.22
CMS 470	-0.35	0.20	-0.10	0.21	0.60	-0.06	-0.25	0.31	5.57	1.53
CMS 471	0.40	0.08	0.15	-0.16	1.10	0.95	0.00	0.23	8.82	4.60
CMS 472	0.65	0.33	-0.10	0.05	0.85	-0.14	0.00	-0.40	11.52	2.68
ZQP 102	0.65	0.16	0.15	-0.04	-0.15	-0.06	0.00	0.23	8.20	3.54
CMS 52	-0.10	0.24	0.40	0.13	-0.65	-0.10	-0.25	0.02	1.90	0.54
BR 473	-0.60	0.12	-0.35	-0.08	-0.65	-0.51	-0.25	-0.35	-13.19	-5.51

$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$	$\hat{\mu}$	$\hat{d}$	$\hat{\bar{h}}$
3.621	-0.131	-0.498 -13.75%	2.038	0.035	0.238 11.67%	2.556	-0.160	0.020 0.78%	2.935	-0.062	0.333 11.34%	17.786	-2.053	-8.527 -47.94%

populations. Ranking the populations according to positive GCA for grain yield in a decreasing order resulted in CMS 474, ZQP 103 and ZQP 101 populations within the dent group and BR 473, CMS 455C, CMS 453, CMS 52, CMS 455 and CMS 458 within the flint group. The estimates of the GCA effects for the other assessed traits are also shown in Tables 3 and 5. The use of each one of these traits in population selection will depend on the specific objectives of each program and the most relevant problems in each case.

If the breeder wants a composite for use *per se* or as a base in an intrapopulation recurrent selection program, the combination of flint and dent populations to form a composite can be recommended. In such case, the additive gene action detected by the effects of varieties and the non-additive effects detected by the variety heterosis could be exploited. In programs designed to obtain inbred lines or in reciprocal recurrent selection programs, the composites should be formed only with populations that have the same grain type to maintain the heterosis groups. In these programs, the potential for heterosis exploitation would be maximized when the hybrids among these composites were synthesized or the lines extracted from them were combined.

CONCLUSIONS

Dominance effects are more important in the expression of grain yield than of other traits in the assessed populations.

The dent CMS 474 and ZQP 101 populations, and the flint CMS 453, BR 473, CMS 455C, CMS 455 and CMS 458 populations are recommended as parents with high potential in intrapopulation selection programs for yield.

The flint BR 473 and CMS 52 populations, and dent CMS 474 and ZQP 103 populations are recommended for a reciprocal recurrent selection program for grain yield.

The dent CMS 474, ZQP 103 and ZQP 101 populations and flint BR 473, CMS 455C, CMS 453, CMS 52 CMS 455 and CMS 458 populations are recommended, in this order, to form composite populations for grain yield.

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RESUMO

HETEROSE E SEUS COMPONENTES EM CRUZAMENTOS DE POPULAÇÕES DE MILHO COM ALTA QUALIDADE PROTÉICA

O presente trabalho teve como objetivo avaliar a heterose e seus componentes, em populações de milho com alta qualidade protéica pertencentes a grupos divergentes, formados com base no tipo de grão. Foi utilizado o modelo de análise para estudo em dialelos parciais, em quatro ambientes. Foram estudadas 19 populações de grãos amarelos quanto a caracteres agronômicos e reação a algumas doenças foliares. Para o caráter produção de grãos houve significância apenas para os efeitos de variedades e de heterose média, indicando que a seleção dos melhores híbridos intervarietais pode ser feita apenas a partir das médias das populações parentais. São recomendadas as populações BR 473 e CMS 52, de tipo duro e CMS 474 e ZQP 103, de tipo dentado, para um programa de seleção recorrente recíproca intergrupos. Para a formação de compostos são recomendadas as populações CMS 474, ZQP 103 e ZQP 101, do tipo dentado, e BR 473, CMS 455C, CMS 453, CMS 52, CMS 455 e CMS 458, do tipo duro, nesta ordem.

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