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ARTICLE

# Heterosis for oil content in maize populations and hybrids of high quality protein

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**ABSTRACT** - *This study aimed to evaluate QPM populations and their crosses for grain oil content to determine the heterosis and its components. Ninety-six hybrids and their 21 parents were analyzed and separated in the groups dent and flint, in the partial diallelic/diallel intergroup scheme. The oil content was extracted from dry matter by the Soxhlet method in three replicates for each genotypic material and attained mean values of 5.04g 100g$^{-1}$ and 4.78g 100g$^{-1}$, respectively, in the groups dent and flint. Among the hybrid crosses, CMS 456 x CMS 463 (6.84g 100g$^{-1}$) presented the highest value. Although the average heterosis (-9.83%) indicates average dominance of the alleles for low oil content, combinations with positive total heterosis were observed. In this sense, the best populations under the focus of improvement for high oil content were ZQP101 and ZQP103, both of the dent group, and CMS52, BR473, CMS455c and CMS465 of the flint group. Hence, it was concluded that there is genetic variability and significant heterosis in the genotypes under study.*

**Key words**: QPM, maize, nutritional quality, diallel.

## INTRODUCTION

In alimentation, a good diet contains adequately balanced proteins, carbohydrates and lipids, apart from minerals and vitamins. These nutrients are essential for man as well as for animals and vital for the growth and development of plants. In this aspect, plants are insufficient, since there is no single species that would hold all nutrients in suitably balanced proportions and in satisfactory quantity. In spite of being an excellent carbohydrate source, maize has low oil and protein contents. On the other hand, it has a high genetic variability which would make the selection of plants with a high oil content potential possible, as pointed out in some studies Sprague and Brimhall 1949 (Mendes 1972, Mittelmann 2003).

It is known that the current requirements for industrial maize processing demand large, flint and orange-colored grains, with a high oil content. Studies related to the grain oil content have become more and more important, in view of their applications in the human and animal alimentation and of the high energy content of the oil.

Maize is commonly used in animal feeding as energy source, owing to its high starch content, available in a readily digestible and cheap form, which gives it priority over all other cultivated cereals. However, in terms of oil content, the mean proportion of only 4.3% presents deficiency. It is exceeded by far by the values found in other grains such as soybean (17.7%), sunflower (50.2%), peanut (44.8%), sesame (52.2%) and others (IBGE 1977).

Mendes (1972), who studied some traits in maize varieties of the South, Center-South, Center-West and Northeast regions in Brazil, verified that the most

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expressive results in oil content were achieved in the Southern region, with a subtropical, wet and mesothermic climate. Ruschel (1975), who worked with *opac-2* maize, observed a wide variation in the grain oil content (3.58 to 8.35%), indicating that selection to improve the nutritional maize quality in this aspect could be successful.

Maize cultivars of high protein quality (quality protein maize-QPM) have been cited as an alternative of an improved nutritional quality of this cereal for human and monogastric animal feeding (Tosello 1987). Along with the protein quality, the increase in the oil content could represent a quality differential, principally with a view to genotypes for family agriculture. In this context and considering the increasing importance of maize in oil production, our study aimed to evaluate QPM populations and their crosses for the grain oil content, determining the heterosis and its components as support for breeding of populations *per se* or composite formation for a recurrent selection program.

## MATERIAL AND METHODS

Twenty-one yellow-grain QPM populations in Hardy-Weinberg equilibrium were used, derived from genebanks of the Embrapa Milho e Sorgo (CNPMS) and Zeneca Seeds company. In order to establish distinct heterotic groups, the populations were separated according to the grain type in eight populations of dent grains (group 1) and thirteen populations of flint grains (group 2). They were crossed in a partial diallel intergroup scheme, according to Miranda Filho and Geraldi (1984), and 104 hybrids were generated. Of all these, eight were discarded due to problems with seed insufficiency. The populations CMS 456, CMS 464 and CMS 466, all of group 1, were discarded for the same reason. The characteristics of the populations under study are displayed in Table 1.

The 18 parent populations and 96 $F_1$ hybrids were planted in the growing season 2000/2001, on an experimental area of the Escola de Agronomia e Engenharia de Alimentos of the Universidade Federal de Goiás, county of Goiânia, state of Goiás (lat 16º 35' 12" S, long 49º 21' 14" W, alt 730 m asl), Brasil. The fertilization met the general recommendations for maize. Each plot consisted of one 10 m long row with five plants per meter (50 plants). In every row the plants were manually pollinated with a pollen mixture of at least five plants of the same row and individually protected from pollen contamination from other genotypic materials. By this procedure grains of the $F_2$ generation of each hybrid were simultaneously obtained, which corresponds to the grain type harvested by the farmer and the seed renovation of the parent populations.

For the analysis of the oil content 100 g grain samples of each material were used that were insect, fungus and rot-free and that presented uniform moisture and no mechanical damages at all. The seeds were ground in a Willye type mill and thereafter, sifted through a 0.42mm (ABNT 40 and Tyler 35) mesh sieve. The powder obtained this way was filled into plastic bags and deep-frozen until the laboratory analyses. The Soxhlet method (AOAC 1995) was used for extraction. This method is normally used to quantify oil and fat contents in foods and is based on the determination of oil extracted by a solvent. In this case, the dry matter was evaluated, using three laboratory replicates of each material per sample.

For the diallel analysis of data, the total number of treatments is given by: N=p + q+pq-k, where p and q are the parental numbers of dent and flint groups, and k the number of lost data. In the present case, the number of treatments evaluated was N = 114, due to the lost data of three parents and eight crosses. The adopted statistic model was that of Miranda Filho and Geraldi (1984), adapted to a partial diallel, based on the complete diallel model of Gardner and Eberhart (1966). In this model, the mean of a cross involving one parent i (i = 1,2,...,p) and a second parent j (j = 1,2,...,q) of two fixed variety groups (groups 1 and 2), is given by:

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

where: μ is the mean point between the means of the two variety groups; d is the measure of the difference between the means of the two groups of varieties; $v_i$ and $v_j$ are the variety effects of group 1 and 2, respectively; $\bar{h}$ is the average heterosis of all crosses; $h_i$ and $h_j$ are the heterosis variety effects of group 1 and 2, respectively; $S_{ij}$ is the specific heterosis of the cross between populations i and j; and $\bar{\varepsilon}_{ij}$ is the mean experimental error associated to the observed means $Y_{ij}$, assumed with normal distribution, null mean and constant variance $\sigma^2$. The indicator variables α and θ assumed the values: α and θ=1 for the hybrids; α =1 and θ = 0 for the parent varieties of group 1 with $Y_{ij}$=$Y_{ii}$; or

**Table 1**. Characterization of the yellow maize QPM populations used in the study

| BAG[1] Identification | Identity | Grain type | Origin[2] |
|---|---|---|---|
| CMS 453 | Population 65 - Yellow Flint QPM | Flint | CIMMYT |
| CMS 454 | Population 66 - Yellow Dent QPM | Dent | CIMMYT |
| CMS 455 | Pool 25 QPM | Flint | CIMMYT |
| CMS 455C | Synthetic of 455 | Flint | CNPMS |
| CMS 456 | Pool 26 QPM | Dent | CIMMYT |
| CMS 458 | Amarillo Cristalino QPM | Flint | CIMMYT |
| CMS 463 | Population 69 - Templado Amarillo QPM | Flint | CIMMYT |
| CMS 464 | Population 70 - Templado Amarillo QPM | Dent | CIMMYT |
| CMS 465 | Pool 33 QPM | Flint | CIMMYT |
| CMS 466 | Pool 34 QPM | Dent | CIMMYT |
| CMS 467 | Amarillo del Bajío QPM | Dent | CIMMYT |
| CMS 468 | Amarillo Subtropical QPM | Flint | CIMMYT |
| CMS 470 | Obregón 7941 | Flint | CIMMYT |
| CMS 471 | Across 7941 | Flint | CIMMYT |
| CMS 472 | San Jerónimo 7941 | Flint | CIMMYT |
| CMS 473[3] | Yellow Synthetic QPM | Flint | CNPMS |
| CMS 474 | (75%) CMS454 : (25%) BR-106 | Dent | CNPMS |
| CMS 52[4] | Superearly Yellow Synthetic QPM | Flint | CNPMS |
| ZQP 101[5] | Population 89/Yellow dent QPM | Dent | Zeneca |
| ZQP 102[5] | Population 91/HD1 | Flint | Zeneca |
| ZQP 103[5] | Population 88/4876 – pop. 66 | dent | Zeneca |

[1] BAG: Active Germplasm Bank; [2] CIMMYT (Centro Internacional de Mejoramiento de Maíz y Trigo); CNPMS (Centro Nacional de Pesquisa de Milho e Sorgo da Embrapa) and Zeneca Seeds Ltda; [3] released as BR 451; [4] Released as BR 473 and [5] Populations of the Zeneca seed Ltda company

$\alpha = -1$ and $\theta = 0 =$ for the varieties of group 2 with $Y_{ij}=Y_{jj}$. Furthermore, the following parametric restrictions were assumed: $\sum_i v_i = \sum_j v_j = \sum_i h_i = \sum_j h_j = 0$ and $\sum_i s_{ij} = 0$, $\sum_j s_{ij} = 0$.

For the estimation of the model effects and their respective sums of squares, the ordinary least squares method was used, based on the system of normal equations, with a matrix solution given by: $\hat{\beta} = (X'X)^{-1} X'Y$ ; where, $\hat{\beta}$ is the vector with the parameter estimates of the model, X is the information matrix of coefficients of the model effects and Y is the vector of the observed means.

Since the diallel table was not complete (some lost treatments), the models were sequentially adjusted to evaluate the contribution of each source of variation to the total variability. Eight models (sub-models of the original model), with successive inclusion of parameters associated to each source of variation were considered. Their respective sums of squares (SS) were calculated by the general formula: $SS = \hat{\beta}'X'Y$ , with as many degrees of freedom as the considered model had parameters. Thus, the sum of squares of each source of variation in the analysis of variance was calculated by the difference between the sums of squares of the model with inclusion of the respective source and the one reduced for the same effect. Besides, the general combining ability of each parent ($g_i$ and $g_j$) was estimated, corresponding to method 4 of Griffing (1956), using the expressions: $\hat{g} = \frac{1}{2}\hat{v}i + \hat{h}_i$ and $\hat{g}_j = \frac{1}{2}\hat{v}_j + \hat{h}_j$ .

All statistical calculations were implemented in the software SAS (Statistical Analysis System), using the routine developed in the IML procedure (SAS Institute 2002).

## RESULTS AND DISCUSSION

The results of the diallel analysis for grain oil content are presented in Table 2. All parameters of the model showed significant effects, with exception of the difference between means of the two parental groups.

**Table 2**. Analysis of variance according to the partial diallel model of Miranda Filho and Geraldi (1984) for grain oil content (g $100g^{-1}$) of QPM parents of dent grains (group 1) and of flint grains (group 2) and their hybrid combinations

| Source of variation | df | MS | Prob > F |
|---|---|---|---|
| Replicates | 2 | 0.0730 | - |
| Genotypes | 113 | 0.6420 | < 0.0001 |
| Varieties Group 1 ($G_1$) | 4 | 2.8635 | < 0.0001 |
| Varieties Group 2 ($G_2$) | 12 | 0.7819 | < 0.0001 |
| $G_1$ vs $G_2$ | 1 | 0.0536 | 0.1140 |
| Heterosis (H) | 96 | 0.5349 | < 0.0001 |
| Mean H. | 1 | 2.7114 | < 0.0001 |
| H. $G_1$ | 4 | 0.8966 | < 0.0001 |
| H. $G_2$ | 12 | 0.3844 | < 0.0001 |
| Specific H. | 79 | 0.5108 | < 0.0001 |
| Error[1] | 226 | 0.0213 | - |
| CV (%) | - | 5.5905 | - |

[1] Experimental error estimated at the mean level of three replicates

The significance for the effect of varieties within the two groups confirms the existence of genetic variability for the trait in the parents. This fact reinforces the possibility of selection of superior populations for oil content among the evaluated QPM populations. This strategy, associated with selection for agronomical traits, would represent an alternative for the start of a recurrent selection program.

The maize grain oil contents are under polygenic genetic control, presenting quantitative segregation, with predominance of additive effects (Dudley et al. 1977, Miller et al. 1981). This fact indicates the need of continuous selection for the improvement of this trait, which can be eased by broadening the genetic base.

The analysis of variance according to the partial diallel model also permits, among other aspects, an in-depth investigation of the phenomenon of heterosis, partitioning it in its components. The average heterosis, variety heterosis of the groups dent and flint and specific heterosis were significant (Table 3). The existence of heterosis indicates divergence in the gene frequencies between the varieties of the two groups, in at least part of the loci with dominance involved in the trait control (Vencovsky, 1987). The specific heterosis is expressed due to the existence of sufficiently great differences between the average gene frequencies of at least part of the varieties, or differences between complementary degrees of frequencies in hybrid combinations. According to Vencovsky and Barriga (1992), gene complementation is the phenomenon where two parents complement one another, restraining the deficiencies in the hybrid at the genome level. Complementation occurs when one of the parents in the locus set has some loci with a low frequency of favorable alleles and, in exactly the same loci, the other has high allele frequencies. The sensitivity of specific heterosis only detects divergence in loci with dominance (Vencovsky 1987).

The overall mean of the grain oil content was 4.52g $100g^{-1}$ (Table 3), which is higher than the mean values found in the literature for normal maize, between 3.50 and 4.50g $100g^{-1}$ (Alexander 1986, Lima et al. 2000, Tosello 1987). In this case, higher means than those reported were observed in the parents as much as in the hybrids. The parent means in the groups dent and flint were 5.04g $100g^{-1}$ and 4.78g $100g^{-1}$, respectively, while the hybrid mean was 4.43g $100g^{-1}$, with a top value of 6.84g $100g^{-1}$ (CMS 456 x CMS 463) and a minimum value of 2.69g $100g^{-1}$ (CMS 466 x CMS 470). This shows the great variability between the means, in the parents as much as in their hybrid combinations, compared to data reported in the literature.

The analysis of the variety effects ($v_i$ and $v_j$) and variety heterosis ($h_i$ and $h_j$) estimates (Table 4) demonstrates the great heterogeneity among the parents. In relation to the effect of varieties, the best populations *per se* in group 1 were ZQP 101 (1.02g 100 $g^{-1}$) and ZQP 103 (0.90g $100g^{-1}$), and in group 2, CMS 52 (1.50g $100g^{-1}$), BR 473 (1.23g $100g^{-1}$), CMS 455c (0.77g $100g^{-1}$) and CMS 465 (0.65g $100g^{-1}$). For the variety heterosis effect the genotypes CMS 474 (0.51g $100g^{-1}$),

**Table 3**. Matrix of means (g $100g^{-1}$) of the oil content in maize populations of high protein quality and their crosses

| G1/G2[1] | CMS453 | CMS455 | CMS455 | CMS458 | CMS463 | CMS465 | CMS468 | CMS470 | CMS471 | CMS472 | ZQP102 | CMS52 | BR473 | $\overline{Y}^2_{io}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CMS454 | - | - | - | - | 2.9393 | 4.0514 | 3.5638 | 4.2459 | 4.1080 | 5.3759 | 4.2675 | 3.8585 | 4.8473 | 4.7509 |
| CMS456 | - | - | - | - | 6.8424 | 4.3156 | 5.2355 | 3.9404 | 4.4786 | 3.4652 | 4.3022 | 5.0381 | 4.5789 | - |
| CMS464 | 4.3157 | 4.1354 | 5.3925 | 5.3281 | 3.9682 | 4.9697 | 5.0609 | 3.7783 | 4.6487 | 5.4558 | 4.5627 | 4.7748 | 3.6474 | - |
| CMS466 | 5.0497 | 4.0409 | 4.4285 | 4.5094 | 4.3042 | 3.7175 | 3.3879 | 2.6871 | 3.4365 | 3.6477 | 4.3717 | 3.6309 | 3.1604 | - |
| CMS467 | 3.3911 | 4.3713 | 3.9095 | 4.3310 | 4.2695 | 4.3033 | 3.7631 | 3.6484 | 3.6480 | 4.5216 | 3.6994 | 5.1790 | 4.9714 | 4.0514 |
| ZQP101 | 5.1905 | 4.1873 | 3.8875 | 4.7101 | 3.8765 | 4.5862 | 4.6727 | 3.7796 | 4.8407 | 2.7170 | 4.0815 | 4.3935 | 4.5864 | 6.0422 |
| ZQP103 | 5.4648 | 5.6445 | 5.3547 | 5.1132 | 6.0355 | 4.9078 | 5.6971 | 4.9473 | 4.9491 | 4.5571 | 4.8897 | 4.3130 | 6.1249 | 5.9252 |
| CMS474 | 5.8146 | 5.4674 | 4.9283 | 4.0481 | 4.7335 | 5.1921 | 3.8686 | 4.0178 | 3.8332 | 4.3272 | 3.7121 | 4.3840 | 5.9528 | 4.4180 |
| $\overline{Y}^2_{0j}$ | 4.0962 | 4.8351 | 5.5546 | 5.0192 | 4.4624 | 5.4296 | 4.4013 | 3.6116 | 4.2717 | 4.2919 | 3.8664 | 6.2782 | 6.0050 | 4.5182[3] |

[1] G1 and G2: Parents of the groups of dent and flint grain varieties respectively; [2] $\overline{Y}^2_{io}$ and $\overline{Y}^2_{0jj}$: means of the parents of group 2 and [3] Overall mean

**Table 4**. Matrix of the estimates of specific heterosis ($S_{ij}$), variety effects ($\hat{v}_i$ and $\hat{v}_j$), variety heterosis ($\hat{h}_i$ and $\hat{h}_j$), general combining ability ($\hat{g}_i$ and $\hat{g}_j$), means of the variety groups ($\hat{\mu}$), deviation between the group ($\hat{d}$) and mean heterosis (h) for the trait oil content (g $100g^{-1}$) in yellow grain maize populations of high protein quality

| G1/G2[1] | CMS453 | CMS455 | CMS455c | CMS458 | CMS463 | CMS465 | CMS468 | CMS470 | CMS471 | CMS472 | ZQP102 | CMS52 | BR473 | $\hat{v}_i$ | $\hat{h}_i$ | $\hat{g}_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CMS454 | - | - | - | - | -1.4810 | -0.2532 | -0.6415 | 0.5662 | 0.0660 | 1.3183 | 0.2856 | -0.2817 | 0.4574 | -0.2723 | -0.0608 | -0.1970 |
| CMS456 | - | - | - | - | 2.2614 | -0.1498 | 0.8694 | 0.0999 | 0.2758 | -0.7531 | 0.1595 | 0.7371 | 0.0282 | - | - | - |
| CMS464 | -0.4752 | -0.4256 | 0.8225 | 0.7349 | -0.6128 | 0.5043 | 0.6948 | -0.0622 | 0.4459 | 1.2375 | 0.4200 | 0.4738 | -0.9033 | - | - | - |
| CMS466 | 0.2588 | -0.5201 | -0.1415 | -0.0838 | -0.2768 | -0.7479 | -0.9782 | -1.1534 | -0.7663 | -0.5706 | 0.2290 | -0.6701 | -1.3903 | - | - | - |
| CMS467 | -1.1530 | 0.0571 | -0.4137 | -0.0154 | -0.0647 | 0.0848 | -0.3562 | 0.0547 | -0.3079 | 0.5501 | -0.1965 | 1.1248 | 0.6675 | -0.9718 | 0.2076 | -0.2783 |
| ZQP101 | 0.7162 | -0.0571 | -0.3659 | 0.4335 | -0.3879 | 0.4375 | 0.6232 | 0.2557 | 0.9546 | -1.1847 | -0.1689 | -0.4341 | -0.7906 | 1.0190 | -0.8576 | -0.3481 |
| ZQP103 | -0.1556 | 0.2540 | -0.0448 | -0.3095 | 0.6250 | -0.3871 | 0.5015 | 0.2773 | -0.0832 | -0.4907 | -0.0825 | -0.8175 | 0.7447 | 0.9020 | 0.3470 | 0.7980 |
| CMS474 | 0.7879 | 0.6707 | 0.1225 | -0.7808 | -0.0833 | 0.4910 | -0.7332 | -0.0584 | -0.6053 | -0.1269 | -0.6664 | -0.1527 | 1.1663 | -0.6052 | 0.5068 | 0.2042 |
| $\hat{v}_j$ | -0.6825 | 0.0564 | 0.7759 | 0.2405 | -0.3163 | 0.6509 | -0.3774 | -1.1671 | -0.5070 | -0.4868 | -0.9123 | 1.4995 | 1.2263 | - | - | - |
| $\hat{h}_j$ | 0.7339 | 0.1346 | -0.2162 | 0.0747 | 0.3402 | -0.2591 | 0.1558 | 0.0251 | 0.0573 | 0.0628 | 0.1999 | -0.8477 | -0.4614 | - | - | - |
| $\hat{g}_j$ | 0.3927 | 0.1628 | 0.1718 | 0.1949 | 0.1821 | 0.0664 | -0.0329 | -0.5585 | -0.1962 | -0.1806 | -0.2563 | -0.0980 | 0.1518 | - | - | - |

[1] G1 and G2: Parents of the groups of varieties of dent and flint grains, respectively; $\hat{\mu}$ = 4.9010; $\hat{d}$ = 0.1223; $\overline{h}$ = -0.4817 (-9.83%)

ZQP 103 (0.35g $100g^{-1}$) and CMS 467 (0.21g $100g^{-1}$) stood out in group 1 and the populations CMS 453 (0.73g $100g^{-1}$), CMS 463 (0.34g $100g^{-1}$), ZQP 102 (0.20g $100g^{-1}$), CMS 468 (0.16g $100g^{-1}$) and CMS 455 (0.13g $100g^{-1}$) in group 2.

The analysis of maize oil content of several studies agrees with the variability we observed, resulting in different concentrations in different populations and hybrids. Lima et al. (2000), analyzing some Brazilian hybrids, found values between 3.6g $100g^{-1}$ and 6.9g $100g^{-1}$. In another study on the genetic variation for nutritional quality in maize with normal endosperm, Mittelmann (2003) found values between 3.77g $100g^{-1}$ and 5.10g $100g^{-1}$. Besides, these results of the literature indicate that the QPMs analyzed in the present study have the potential to compose new base populations, *per se* or in crosses, aiming at the improvement for a high grain oil content.

The average heterosis value was negative (-0.48g $100g^{-1}$), corresponding to -9.83% (Table 4). In this case, despite the significance demonstrates the existence of differences between the hybrids and parents, the heterotic effect acts in the opposite sense to the desired, that is, in some hybrids there is a reduction in the grain oil content, compared to the parent mean. This fact shows the mean dominance of the alleles for low oil content. In spite of the negative mean heterosis, different combinations with total positive heterosis can be observed. This demonstrates the existence of bidirectional dominance for the trait in the different loci, with prevalence of loci with dominance for reduction of the oil content. In a program targeting hybrids, the strategy would therefore be to select combinations with positive heterosis. This situation would indicate parent pairs that are divergent precisely in the loci with dominance for high oil content.

The contribution of a given parental population to the mean of a composite is proportional to the index $I'_j = \frac{1}{2}v_j + (\frac{k-1}{k})h_j$, which approaches the general combining ability ($g_j$) for higher k values, being k the number of parents of the composite (Miranda Filho and Chaves 1991). The parents that stood out with values of general combining ability (Table 4) were ZQP 103 (0.80g $100g^{-1}$) and CMS 474 (0.20g $100g^{-1}$) in the group dent and CMS 453 (0.39g $100g^{-1}$), CMS 458 (0.19g $100g^{-1}$), CMS 463 (0.18g $100g^{-1}$), CMS 455c (0.17g $100g^{-1}$), CMS 455 (0.16g $100g^{-1}$) and BR 473 (0.15g $100g^{-1}$) in the group flint. These populations can be indicated for the formation of base populations for a recurrent selection program or extraction of lines for hybrid formation, targeting QPM cultivars with high grain oil content.

The highest grain oil contents (Table 3) were verified in the hybrids CMS 456 x CMS 463 (6.84g 100 $g^{-1}$), ZQP 103 x BR 473 (6.12g $100g^{-1}$), ZQP 103 x CMS 463 (6.03g $100g^{-1}$), CMS 474 x BR 473 (5.95g $100g^{-1}$) and CMS 474 x CMS 453 (5.81g $100g^{-1}$). Although the concordance between the best hybrids and those with highest estimates of specific heterosis was not perfect (Table 4), the hybrid combination that was best for specific heterosis was also best for the mean oil content. This intervariety hybrid (CMS 456 x CMS 463) is therefore promising for the trait under study.

Considering the objectives of intra and interpopulation improvement simultaneously, relatively to the estimated general combining abilities for oil content, the parents CMS 474 and CMS 454 stood out in the group dent and CMS 455, CMS 465, CMS 455c and CMS 463 in the group flint. Based on agronomic traits, including grain yield, Rodrigues and Chaves (2002) recommended the populations CMS 474, ZQP 103 and ZQP 101 (group 1) and the populations BR 473, CMS 455C, CMS 453, CMS 52, CMS 455 and CMS 458 (group 2), in this order, for the formation of composites. On the other hand, in terms of protein quality, Oliveira et al. (2004) emphasized the quality of the populations CMS 454, CMS 474 and ZQP 103 (group1) and of the populations CMS 453, BR 473, CMS 463, CMS 458 and ZQP 102 (group 2). So two populations of the group dent (CMS 474 and CMS 454) and three of the group flint (CMS 455, CMS 455c and CMS 463) coincide in the grain oil content and in their good agronomic and protein performance. These genotypes therefore own the potential for selection in a breeding program aiming at the formation of composites or the development of lines for hybrid formation.

## CONCLUSIONS

1. There is genetic variability in the QPM maize populations under study for grain oil content.

2. There is heterosis expression for grain oil content, with negative average heterosis.

3. The populations CMS 474, CMS 454, CMS 455, CMS 465, CMS 455C, and CMS 463 are indicated for the formation of base populations for grain oil content breeding.

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# Heterose para teor de óleo em populações e híbridos de milho de alta qualidade protéica

**RESUMO -** *Este trabalho objetivou avaliar populações QPM e seus cruzamentos, quanto ao teor do óleo no grão, determinando-se a heterose e seus componentes. Foram analisados 96 híbridos e seus 21 genitores, divididos em grupos dentado e duro, no esquema dialélico parcial intergrupos. Extraiu-se o teor de óleo da matéria seca pelo método Soxhlet, utilizando-se três repetições para cada material. No grupo dentado e duro a média foi de 5,04g 100g$^{-1}$ e 4,78g 100g$^{-1}$, respectivamente. Dentre os híbridos o maior valor foi do cruzamento CMS 456 x CMS 463 (6,84g 100g$^{-1}$). Embora a heterose média (-9,83%) indique que há dominância média dos alelos para baixo teor de óleo, foram observadas combinações com heterose total positiva. Nesse sentido as melhores populações visando melhoramento para alto óleo foram ZQP101 e ZQP103, do grupo dentado, e CMS52, BR473, CMS455c e CMS465, do grupo duro, concluindo-se que existe variabilidade genética e heterose significativa entre os materiais estudados.*

**Palavras-chave**: *QPM, milho, qualidade nutricional, dialelo.*

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