Revista Brasileira de Milho e Sorgo

Brazilian Journal of Maize and Sorghum

ISSN 1980 - 6477

Journal homepage: www.abms.org.br/site/paginas

AGRONOMIC PERFORMANCE OF MAIZE HYBRIDS DERIVED FROM DOUBLED HAPLOID LINES COMPARED TO CONVENTIONAL HYBRIDS

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How to cite

LOURENÇONI, L. J.; TRINDADE, R. S.; RIBEIRO, L. C. A.; PARRELLA, N. N. L. D.; GUIMARÃES, P. E. O.; GUIMARÃES, L. J. M.; TRINDADE, B. M. C.; RIBEIRO, M. R. Agronomic performance of maize hybrids derived from doubled haploid lines compared to conventional hybrids. **Revista Brasileira de Milho e Sorgo**, v. 20, e1218, 2021.

Abstract – The objective of this work was to use the partial diallel methodology to compare double-haploid lines (DHs) of maize with lines obtained by traditional methods. To obtain hybrids, five double-haploid lines, used as female parents, were crossed with four testers, as male parents. Twenty hybrids were obtained from double-haploid lines, being: 8 experimental, and 8 commercial from Embrapa and 4 from other companies. Were evaluated; final stand (ST), tipping and breaking (LODG), plant height (PH), ear insertion height (EH), grain moisture at harvest (GM) and total grain weight (YIELD). Analysis of variance was performed, unfolding the degrees of freedom of the genotype, Tukey test at 5% probability, and the decomposition of the sums of squares of the treatments into general and specific combining ability for testers and DH lines. PH and EH were higher in hybrids derived from DHs lines, while productivity and final stand were higher in experimental controls. However, some hybrids, such as the hybrid DH1800007 presented higher YIELD than commercial and experimental controls. The data obtained demonstrate that hybrids derived from double-haploid lines, in addition to accelerating the time to obtain new cultivars, enable the development of hybrids with superior agronomic performance.

Keywords: *Zea mays* L, Haploid induction, partial diallel.

DESEMPENHO AGRONÔMICO DE HÍBRIDOS DE MILHO DERIVADOS DE LINHAGENS DUPLO-HAPLOIDES COMPARADO COM HÍBRIDOS CONVENCIONAIS

Resumo - O objetivo deste trabalho foi utilizar a metodologia do dialelo parcial para comparar linhagens duplo-haploides (DHs) de milho com linhagens obtidas por métodos tradicionais. Para obtenção de híbridos foram cruzadas cinco linhagens duplo-haploides, utilizadas como genitores femininos, com quatro testadores, como genitores masculinos. Foram obtidos 20 híbridos a partir de linhagens duplo-haploides, sendo: 8 experimentais, e 8 comerciais da Embrapa e 4 de outras empresas. Foram avaliados; estande final (ST), tombamento e quebramento (LODG), altura de planta (PH), altura de inserção da espiga (EH), umidade de grãos na colheita (GM) e peso total de grãos (YIELD). Efetuou-se análise de variância, desdobrando os graus de liberdade de genótipo, teste Tukey a 5% de probabilidade, e a decomposição das somas de quadrados dos tratamentos em capacidade geral e específica de combinação para testadores e linhagens DH. PH e a EH foram maiores nos híbridos derivados de linhagens DHs, enquanto que a produtividade e o estande final foram superiores nas testemunhas experimentais. Porém, alguns híbridos, como o híbrido DH1800007 apresentaram YIELD superior às testemunhas comerciais e experimentais. Os dados obtidos demonstram que híbridos derivados de linhagens duplo-haploides, além de acelerar o tempo de obtenção de novas cultivares, possibilitam o desenvolvimento de híbridos com desempenho agronômico superior.

Palavras-chave: *Zea mays* L, Indução de haploidia, Dialelo parcial.

DOI: https://doi.org/10.18512/rbms2021v20e1218

Maize (*Zea mays* L.) is grown in various regions of the world, occupying an area of around 160 million hectares (Silva et al., 2017). In Brazil, maize is grown in two different crop seasons: the first crop or summer crop season sown within the months of September to November, the period in which there is the greatest rainfall, and the second crop, also called "safrinha", sown within the months of January to March, after the summer crop (IBGE, 2019; Conab, 2021).

In maize breeding, lines are the most important input for development of new cultivars (Trindade et al., 2019). Also called inbred or pure lines, these genotypes have most of their loci in homozygosity, serving as a vehicle for introgression of traits of interest and for obtaining superior hybrids through expression of heterosis, synthetic varieties, and other types of cultivars (Guimarães et al., 2018).

In maize, crosses are made between lines of different heterotic groups to increase heterosis by genetic divergence. The heterotic groups most used in maize for crosses in Brazil are the dent group and the flint group, originating from Tuxpeno and Cateto open pollination varieties, respectively (Paterniani & Campos, 2005).

New maize cultivars are generated in seed multiplication fields in processes that include self-fertilizations, manual crosses, and crosses in isolated fields. The traditional manner of obtaining maize lines is through consecutive self-fertilizations so as to achieve complete homozygosity of the plant. This requires around 7 to 8 generations, with a 50% increase in homozygosity with each self-fertilization generation. This process becomes complex since it is laborious and costly and requires many cycles.

To accelerate the process of obtaining maize lines and, consequently, maize cultivars, auxiliary techniques can be used in breeding, such as the technology of producing doubled haploid lines. The doubled haploid (DH) line technology is a methodology that aims at reducing time in obtaining homozygous lines, based on generation of haploid individuals and later duplication of their genome in a spontaneous or artificial manner (Chase, 1952; Prigge & Melchinger, 2012).

To obtain haploids in maize, the *in vivo* protocol is the method most used, which consists in crossing source-populations with haploid inducers (Prigge & Melchinger, 2012). Haploid inducers are genotypes that have the ability of inducing the formation of seeds with haploid embryos whose constitution is based on the source-genotype genes. After chromosomal duplication, these plants are self-fertilized and come to be called doubled haploid lines, since for each chromosome that the haploid plant had before, it comes to have an exact copy, which confers it with complete homozygosity and the same number of chromosomes as a diploid plant (Prigge; Melchinger, 2012; Trindade et al., 2019). This technique reduces the process of obtaining homozygous lines by a year and a half (3 generations) and makes it possible to obtain lines with genetic uniformity and stability, with the added result of wide variability among the progenies obtained, making selection among families more effective.

Nevertheless, after DH lines are obtained, they must be evaluated as parental lines of hybrids, as occurs with any line. In maize, the process of increasing inbreeding leads to reduction in vigor in allogamous varieties, and agronomic superiority must be identified. General combining ability (GCA) consists of the mean response of a parent in a series of crosses and is associated with the additive effects of the alleles. Specific combining ability (SCA), in turn, represents deviation from the expected response of a given genotype, taking the general combining abilities of its parental lines as a basis, relating to the non-additive effects of dominance and epistasis (Griffing, 1956; Vencovsky & Barriga, 1992; Miranda Filho & Vencovsky, 1999; Hallauer et al., 2010).

There are a series of procedures for evaluating combining ability. The diallel cross methodology is one of the procedures that can be used, which allows identification of parents based on their own genetic values and on the ability of combining in hybrids that produce promising populations (Viana, 2007). A diallel consists of a mating scheme for crossing a group of parents, which can be lines, varieties, clones, etc., resulting in a set of p(p-1)/2 hybrids. In addition to the respective parents, this may include reciprocal hybrids and other related generations, backcrosses, etc. (Kempthorne & Curnow, 1961; Cruz et al., 2004).

Among the methodologies of analysis of diallel crosses are partial diallels (Kempthorne & Curnow, 1961), which involve evaluation of progenies arranged in two groups, whether belonging to a group in common or not, with inferences being made for each group. In partial diallels, the progenitors of a group are represented by constant numbers; however, they can be different from the number of hybrid combinations in which the progenitors of another group are represented. Thus, the aim of this study was to use the partial diallel methodology to compare doubled haploid lines of maize with lines obtained by conventional methods as parents, based on general and specific combining ability and on the agronomic performance of the hybrids obtained from the DH lines.

Materials and Methods

The data used in this study were obtained by the maize breeding program of Embrapa Milho e Sorgo in January 2019. The experiment was conducted at Embrapa Milho e Sorgo in the municipality of Sete Lagoas, in the central region of Minas Gerais, Brazil.

The doubled haploids evaluated were derived from the haploid induction field established in the 2017/18 crop season, in which the source-populations were F_1 hybrids obtained by crosses of elite lines within the same heterotic group. After harvest from the field, haploid seeds were selected in each ear and chromosomal duplication was carried out to obtain doubled haploids of maize.

DOI: https://doi.org/10.18512/rbms2021v20e1218

Hybrids for field tests were obtained by crossing five doubled haploid lines (DH1700402, DH1700358, DH1700356, DH1700388, and DH1700389) used as female parents with the testers CMS M035, CMS M048, CMS M036, and 5702955 used as male parents; the lines CMS M036 and 5702955 were from the dent heterotic group and CMS M035 and CMS M048 from the flint heterotic group.

The crosses were made in isolated lots, with detasseling of all the plants of the female parents so that all the pollen would come only from the tester lines. Twenty (20) hybrids from the doubled haploid lines were obtained from the isolated lots, and these hybrids were evaluated together with other genotypes, namely, 8 experimental hybrids, which had already been evaluated in Value for Cultivation and Use (Valor de Cultivo e Uso - VCU) trials conducted by Embrapa and are in the final phase of registration, and 8 commercial hybrids, registered by Embrapa and from other companies (Table 1).

A randomized block experimental design (RBD) was used with two replications and plots consisting of two rows with the 36 treatments described above, for a total of 144 rows. The experiment was sown in January 2019 in an experimental area at Embrapa Milho e Sorgo. The seeds were mechanically sown using plot planters at a spacing of 4.2 m × 0.70 m, with a sowing density of 5 seeds / linear meter. Fertilization at sowing and in topdressing and all the management practices carried out followed the recommendations for the maize crop: 450 kg ha^{-1} of the fertilizer formulation 8-28-16 for a total of 36 kg of N, 126 kg of P, and 72 kg of K per hectare).

Herbicides and fungicides were used for health requirements of the maize crop. At sowing, the seeds were treated with fungicides (Metalaxyl-M + Fludioxonil, and Thiram + Carboxin). As a preventive measure, fungicides were applied with the active ingredients Azoxystrobin + Cyproconazole when the maize had 8 formed leaves, and the active ingredients Atrazine, Tembotrione, and Methomyl were used when the maize crop had 5 and 8 leaves. Topdressed fertilization was 300 kg ha^{-1} of urea, with 135 kg ha^{-1} of N, which was parceled out in 2 applications, in the four and eight fully expanded leaf stages. According to the National Meteorology Institute (Instituto Nacional de Meteorologia – INMET), accumulated rainfall was 543.20 mm from Jan. 1, 2019 (sowing) to Jul. 25, 2019 (harvest). Some supplemental irrigations of 30 mm were necessary in the weeks in which rains did not occur.

At the end of the experiment in July 2019, the following data were evaluated: final stand (ST = total number of plants per plot), lodged and broken plants (LODG = number of lodged and broken plants per plot), plant height (PH = average height of the plants of the plot, measured from the base of the stem to the point of connection of the flag leaf to the stem, in cm), ear height (EH = average height measured from the base of the stem to the point of connection of the first ear to the stem of the plants of the

Table 1. Commercial, experimental and derived from double-haploid lines hybrids, evaluated in the experiment.

Genotype	Institution
AG8061PRO2	AGROCERES
AG8088PRO2	AGROCERES
BRS1055	EMBRAPA – comercial hybrid
BRS1060	EMBRAPA – comercial hybrid
BRS2022	EMBRAPA – comercial hybrid
BRS3035	EMBRAPA – comercial hybrid
BRS3042	EMBRAPA – comercial hybrid
DKB310PRO2	DEKALB
P30F35VYHR	Pioneer sementes
2B587Hx	Dow Agrosciences
1P2216	EMBRAPA – experimental hybrid
1P2227	EMBRAPA – experimental hybrid
1F640	EMBRAPA – experimental hybrid
1P2214	EMBRAPA – experimental hybrid
1O2106	EMBRAPA – experimental hybrid
1L1411	EMBRAPA – experimental hybrid
DH1800005	EMBRAPA – Hybrid derived from DHs
DH1800007	EMBRAPA – Hybrid derived from DHs
DH1800013	EMBRAPA – Hybrid derived from DHs
DH1800023	EMBRAPA – Hybrid derived from DHs
DH1800032	EMBRAPA – Hybrid derived from DHs
DH1800037	EMBRAPA – Hybrid derived from DHs
DH1800046	EMBRAPA – Hybrid derived from DHs
DH1800076	EMBRAPA – Hybrid derived from DHs
DH1800077	EMBRAPA – Hybrid derived from DHs
DH1800078	EMBRAPA – Hybrid derived from DHs
DH1800079	EMBRAPA – Hybrid derived from DHs
DH1800080	EMBRAPA – Hybrid derived from DHs
DH1800085	EMBRAPA – Hybrid derived from DHs
DH1800086	EMBRAPA – Hybrid derived from DHs
DH1800112	EMBRAPA – Hybrid derived from DHs
DH1800116	EMBRAPA – Hybrid derived from DHs
DH1800117	EMBRAPA – Hybrid derived from DHs
DH1800118	EMBRAPA – Hybrid derived from DHs
DH1800119	EMBRAPA – Hybrid derived from DHs
DH1800125	EMBRAPA – Hybrid derived from DHs

plot, in cm), grain moisture at harvest (= GM in %), and total grain yield (= YIELD, obtained by conversion of kilograms per plot to tons per hectare, standardized to 13% grain moisture). Plots were harvested using a test plot harvester/combine, harvesting 2 rows at a time and automatically recording grain moisture and weight per plot.

For data analysis, analysis of variance was first carried out, in which the degrees of freedom of genotype were decomposed to contrast the variance of the commercial and experimental hybrids (CH) with the hybrids derived from doubled haploid lines (DH). Mean values were also compared by Tukey's test at 5% probability.

Finally, to evaluate the performance of the doubled haploid lines in crosses with flint and dent testers, based on the data derived from analysis of variance for yield, the sum of squares of the treatments was decomposed into general and specific combining ability. The model of Griffing (1956) was adopted for this decomposition, adapted to the partial diallels, without inclusion of the parental lines. The Genes software (Cruz, 2006) was used for all the analyses.

Results and Discussion

There was an effect of genotype for ST, PH, EH, and GM (Table 2), indicating variability for the group of genotypes evaluated in relation to these characteristics. In turn, the decomposition of the degrees of freedom of genotype for commercial and experimental hybrids indicated that this group of genotypes had differences only for PH and EH. This was expected, due to the more advanced level of breeding these genotypes are in (commercial or pre-commercial phase), which entails more intense selection in the initial steps of development and less differentiation of these genotypes for agronomic characteristics such as plant emergence, establishment of stand, yield level, response to diseases, and other characteristics (Paterniani et al., 2008; Ferreira et al., 2009).

The hybrids derived from doubled haploid lines exhibited significant variability for ST, PH, and GM. The main characteristic of DH is maximum homozygosity, which provides maximum variance among families and maximum expression of hybrid vigor (Guimarães et al., 2018; Trindade et al., 2019). The aforementioned can provide an explanation for variations in characteristics such as plant height, stand, and grain moisture, which is related to an early cycle and plant maturity.

The contrast between hybrids derived from doubled haploid lines and commercial and experimental hybrids (DH × CH) indicated significant differences between these two groups for all the characteristics evaluated, except for GM. It is important to consider each characteristic to understand the response in the DH × CH contrast. Consideration of the ST indicates a smaller population of plants for DH compared to commercial and experimental hybrids. A series of factors interferes in formation of stand, beginning with the quality of the seeds and initial take-off

DOI: https://doi.org/10.18512/rbms2021v20e1218

Table 2 - Estimates of mean square, means and genetic components of variance obtained from the evaluation of 36 experimental, commercial and double-haploid-derived hybrids for six traits of agronomic interest. Sete Lagoas - MG, 2019.

Sources of variation	Degrees of freedom	Mean squares					
		ST	LODG	PH (cm)	EH (cm)	GM (%)	YIELD (ton/ha)
Block	1	9.14	3.91	1409.85	654.05	0.03	1.58
Genotypes	36	90.09*	7.37	560.58**	348.99**	0.27**	8.37
Comercial and experimental hybrids (CH)	15	65.63	4.26	518.33**	366.61**	0.17	9.58
Doubled haploids lines hybrids (DH)	19	96.32*	9.90	379.10**	273.27	0.37**	6.52
DH x CH	1	332.43**	3.57*	4824.10**	1598.82*	0.01	27.28*
Error	36	48.27	5.29	146.93	156.83	0.11	5.91
Mean		28.54	2.68	260.50	138.91	11.86	9.28
HCs Mean		30.96	2.43	251.25	133.59	11.87	9.98
DHs Mean		26.69	2.88	267.54	142.97	11.85	8.75
Phenotypic Variance		32.81	0.45	259.16	183.30	0.09	4.79
Genotypic Variance		8.67	0.09	185.69	104.89	0.03	1.83
H^2		26.44	18.94	71.65	57.22	35.89	38.30
CV_g (%)		9.51	21.72	5.42	7.66	1.45	13.57
CV_e (%)		24.34	63.54	4.65	9.01	2.74	26.18

**,*Significant at 1 and 5%, respectively, by the F test; ST = final stand; LODG = lodged and broken plants per plot; PH = plant height; EH = ear height; GM = grain moisture; YIELD = grain yield; H^2 = coefficient of genotypic determination; CVg = coefficient of genetic variation; CVe = experimental variation coefficient of the seedlings up to loss of plants through mechanical damage or pathogens (Henning et al., 2011). In initial stages of selection, greater problems are expected in formation of stand, which is reduced as the progenies advance within a breeding program.

Higher values of LODG were observed for hybrids derived from DH lines, showing a larger number of lodged and broken plants. However, the percentage observed is compatible with that expected in commercial fields (Coimbra et al., 2010). The data indicate higher mean values for PH and EH in hybrids derived from DH in comparison with commercial and experimental hybrids. A reduction in values is desirable for these characteristics. However, this result is expected in initial phases of a breeding program.

It is important to highlight that for all the sources of variation, except for the contrast between hybrids derived from doubled haploid lines versus commercial and experimental hybrids, YIELD effects were not observed. However, for the DH × CH contrast, the yield difference of around one ton per hectare between these two groups was clear, indicating the need for more intense selection in the group of hybrids derived from DH lines, seeking genotypes that draw near the standard observed in commercial hybrids.

The experimental coefficients of variation (CVe) were higher for ST (23.34), LODG (63.54), and YIELD (26.18), denoting high variability of the data obtained for these characteristics, which results from the types of genotypes under testing, ranging from commercial hybrids to experimental genotypes. This variability inherent to the genotypes under study is shown by the genotypic coefficients of variation (CVg), which were considered acceptable within the standards of experimental accuracy for such characteristics (Fritsche-Neto et al., 2012). Furthermore, the genotypic coefficients of determination (H^2) are noteworthy, which are above 50% for PH and EH, indicating that most of the variation in these characteristics is due to gene effects, and that these traits can be improved in the next generations of selection.

The mean values related to the 36 hybrids evaluated in the experiment are shown in Table 3. For ST, the hybrids were classified in two groups of means, with the DKB310PRO2, 1P2214, DH1800007, BRS3042, DH1800032, DH1800046, and BRS3035 hybrids having greater ST, ranging from 36 to 39 plants per plot. However, it is important to highlight that although the DH × CH contrast indicated greater ST for commercial and experimental hybrids (Table 2), the DH1800007, DH1800032, and DH1800046 genotypes, all derived from DH lines, were statistically superior for this characteristic.

The lodging of plants (LODG) ranged from 1 to 7 lodged and/or broken plants per plot, 3% to 18% lodging proportionally. This problem concerns breeders especially in second crop growth, when *veranicos* (unseasonal hot dry weather) occur, which leave plants more fragile and prone to falling, or subject to effects of strong winds. This scenario is more common

DOI: https://doi.org/10.18512/rbms2021v20e1218

in the months of June/July, coinciding with the end of the crop cycle in the Central-West region of Brazil (Landau et al., 2015). However, in the present study, severe impacts of lodging were not observed in the final plant stand or in grain yield.

For PH, there were significant differences among the genotypes, forming four groups of mean values (Table 3). The genotype DH1800080 exhibited greatest plant height (295 cm), whereas 2B287Hx obtained the lowest mean value of PH (218 cm). This result is higher than the values observed by Paterniani et al. (2008) and Ferreira et al. (2009), who evaluated the height of commercial hybrids as ranging from 188 cm to 220 cm. For EH, the genotypes formed two groups of mean values; the hybrid DH1800080 had the highest ear height (163 cm), and DH1800007 had the lowest (110 cm). Studies indicate that plant height may be correlated with grain yield, in which taller plants would also tend to be higher yielding (Paterniani & Campos, 2005; Prasanna, 2012).

GM serves as a reference for early maturity, since it indicates the potential of the grain for harvest after physiological maturity. The hybrids with lowest GM were the genotypes 1P2227, BRS 1060, DH1800080, DH1800085, DH1800112, and DH1800117. Among all the genotypes evaluated, the highest yields (YIELD) were obtained by the hybrids DH1800007, with 13.51 $t.ha^{-1}$, and DH1800032, with 12.50 $t.ha^{-1}$, both derived from DH lines. Although the absence of significance for genotype impedes statistical inference on these data, in absolute terms, these YIELD values are above the results of the highest yielding commercial hybrids of the experiment (BRS3042 – 12.07 $t.ha^{-1}$, DKB310PRO2 – 11.43 $t.ha^{-1}$, and AG8061PRO2 – 11.01 $t.ha^{-1}$), showing the potential of hybrids derived from DH lines regarding grain yield.

However, wide variations in yield are found in the hybrids derived from DH lines (from 5.91 to 13.51 $t.ha^{-1}$), which reinforces the need for careful assessments and assessments in more environments for selection of the best hybrid combinations. Ferreira et al. (2009), Kostetzer et al. (2009), and Souza Júnior et al. (2010) found variability regarding the performance of lines and hybrids in relation to changes in the environment. Another factor is heterosis, which is clear in crosses from distinct heterotic groups (Viana, 2007). In this study, DH lines were crossed with parents from different groups, which may have been a determining factor for the yield values observed.

The estimates of the mean square for combining ability for the six characteristics evaluated in the experiment are shown in Table 4. The effects of crossing indicate no significant differences among the genotypes evaluated, except for yield, showing that there are superior crosses among the parents under study for YIELD. This result indicates that although the initial analysis of variance did not indicate differences among the genotypes (Table 2), the cross between testers and different DH lines resulted in hybrids with different yield performance.

The effects of GCA were non-significant

DOI: https://doi.org/10.18512/rbms2021v20e1218

Table 3. Means of 36 hybrids evaluated in the experiment for six agronomic traits. Sete Lagoas, MG, 2019.

Genotype	ST		LODG	PH (cm)		EH (cm)		GM (%)		YIELD (ton/ha)
AG8061PRO2	33.5	ab	0.5	255	abcd	150	ab	12.2	ab	11.01
AG8088PRO2	27.5	ab	1.0	283	ab	160	ab	11.7	ab	9.47
BRS1055	21.5	ab	1.0	258	abcd	140	ab	11.7	ab	6.97
BRS1060	23.5	ab	2.5	283	ab	150	ab	11.5	b	8.47
BRS2022	23.0	ab	1.5	253	abcd	135	ab	12.3	ab	7.01
BRS3035	38.0	a	7.5	260	abcd	123	ab	12.3	ab	9.84
BRS3042	36.5	a	1.5	245	abcd	120	ab	12.1	ab	12.07
2B587Hx	25.0	ab	2.0	218	D	123	ab	11.7	ab	6.27
DKB310PRO2	37.0	a	3.0	243	bcd	143	ab	12.2	ab	11.43
P30F35VYHR	26.0	ab	4.0	275	abc	153	ab	11.9	ab	8.21
1F640	27.0	ab	3.5	250	abcd	120	ab	11.9	ab	9.42
1L1411	25.5	ab	2.5	275	abc	145	ab	11.6	ab	9.03
1O2106	27.5	ab	6.0	255	abcd	133	ab	11.7	ab	8.86
1P2214	38.0	a	1.0	285	ab	150	ab	11.6	ab	11.91
1P2216	32.0	ab	5.0	258	abcd	155	ab	11.8	ab	11.51
1P2227	29.5	ab	3.0	245	abcd	133	ab	11.4	b	8.59
DH1800005	33.5	ab	2.0	245	abcd	118	ab	12.1	ab	10.66
DH1800007	39.0	a	1.5	230	cd	110	b	11.7	ab	13.51
DH1800013	23.5	ab	1.0	263	abcd	138	ab	12.2	ab	8.61
DH1800023	30.5	ab	2.5	243	bcd	123	ab	12.4	ab	8.44
DH1800032	37.0	a	1.5	263	abcd	143	ab	11.6	ab	12.50
DH1800037	20.5	ab	2.5	250	abcd	138	ab	11.9	ab	5.91
DH1800046	38.5	a	3.5	270	abc	148	ab	11.5	ab	10.97
DH1800076	22.0	ab	1.0	258	abcd	138	ab	12.0	ab	7.42
DH1800077	33.0	ab	2.0	260	abcd	135	ab	11.8	ab	10.10
DH1800078	25.5	ab	3.0	255	abcd	133	ab	12.1	ab	9.38
DH1800079	21.0	ab	1.5	250	abcd	125	ab	12.8	a	7.69
DH1800080	31.0	ab	3.5	295	a	163	a	11.3	b	10.33
DH1800085	25.0	ab	0.0	288	ab	153	ab	11.3	b	9.26
DH1800086	30.0	ab	1.5	275	abc	145	ab	11.5	ab	10.22
DH1800112	26.5	ab	1.0	273	abc	148	ab	11.4	b	9.46
DH1800116	28.5	ab	5.5	273	abc	150	ab	12.0	ab	10.63
DH1800117	31.5	ab	5.0	270	abc	143	ab	11.4	b	8.28
DH1800118	28.0	ab	2.5	251	abcd	140	ab	12.4	ab	8.95
DH1800119	25.0	ab	6.0	265	abcd	153	ab	12.5	ab	8.67
DH1800125	30.5	ab	7.0	283	ab	153	ab	11.7	ab	9.86

Means followed by the same letter do not differ by Tukey test at 5% probability. ST = final stand; LODG = lodged and broken plants per plot; PH = plant height; EH = ear height; GM = grain moisture; YIELD = grain yield.

DOI: https://doi.org/10.18512/rbms2021v20e1218

for the DH group and for the testers evaluated for all the characteristics, indicating additive effects of low magnitude. This may be related to weak performance of most of the DH lines as parents, which would not be contributing to high gains for the following generations. In contrast, significant effects of specific combining ability were observed, denoting that some crosses exhibited performance different from that expected based on their GCA. A determining factor for this result is expression of heterosis, which is clear in crosses from different heterotic groups (Viana, 2007) and in which a specific combination may stand out, generating hybrids with high performance. Although there were no effects of difference among the progenitors (DH lines or testers) for GCA, it is necessary to evaluate the effects of specific combining ability (SCA), which are important in allogamous species for the development of hybrid cultivars. Considering the results obtained, greater focus will be given to the effects of GCA and SCA related to yield.

The effects of SCA were significant for GM and YIELD at the levels of 5% and 1%,

Table 4. Estimates of mean square (MS), general (GCA) and specific combining ability (SCA) for six agronomic traits, and general combining ability (GCA) effects for yield associated with DH lines for Flint and Dent heterotics groups.

SV	DF	MS					
		ST	LODG	PH	EH	GM	YIELD
Crosses	19	381.81	1.92^{ns}	35026.31	9915.26	71.41	105.40*
GCA DHs	4	88.85	1.00^{ns}	11093.75	3278.75	19.20	38.87
GCA Testers	3	141.60*	0.21^{ns}	16226.67	4363.33	41.69	98.67
SCA Hybrids	12	539.52	2.65^{ns}	47703.75	13515.42	96.24*	129.26**
Error	36	48.27	5.29	146.93	156.83	0.11	5.91
Mean (u)	5.5	10.20	0.58	105.00	55.50	4.75	9.47
SD (u)	1.10	1.10	1.10	1.10	1.10	1.10	1.10

GCA effects associated of DHs lines		GCA effects associated of testers	
DHs lines	**YIELD**	**Testers**	**YIELD**
DH1700402	0.575	CMSM035	-1.02
DH1700358	0.825	CMSM048	-0.06
DH1700356	2.975	CMSM036	-3.2
DH1700388	-2.15	5702955	4.28
DH1700389	-2.225		
SD (Gi)	2.20	SD(Gj)	1.90
SD (Gi-Gi’)	3.47	SD(Gj-Gj’)	3.11

**,*Significant at 1 and 5%, respectively, by the F test; SV = sources of variation; SD = standard deviation; DG = degrees of freedom; ST = final stand; LODG = lodged and broken plants per plot; PH = plant height; EH = ear height; GM = grain moisture; YIELD = grain yield.

respectively (Table 4). This indicates that at least one specific combination resulted in hybrids with values different from the others, which, consequently, may be a descendant of a progenitor line with higher GCA. According to Cruz et al. (2004), it can be inferred that the higher the values of SCA, the higher the deviations of dominance and the yield gains obtained from development of the hybrids. Nevertheless, it is important to remember that the results were not significant for GCA effect, either for DH lines or for testers. Therefore, possible contributions of effect of these progenitors to SCA of the hybrids cannot be inferred.

For the effects of general combining ability associated with yield, among the DH lines, the greatest effects were observed for the DH17000356 line. For the testers, the 5702955 line could be identified as the greatest contributor to yield. The significance of crosses for YIELD justifies the selection of these lines for increasing this characteristic, based on the effects of GCA of the progenitors. In this case, of the five DH lines, DH1700356 obtained the greatest effect (2.975) of general combining ability for the YIELD characteristic, followed by DH1700358 (0.825) and DH1700402 (0.575). In relation to the testers under evaluation, the line that had the greatest GCA effect was 5702955 (4.28), whereas the other testers exhibited negative effects for GCA. GCA is a variance component that is important to estimate in maize breeding because it refers to the mean response of a progenitor when tested in a series of hybrid combinations. These values of GCA are associated with additive effects, which lead to gain in generation of hybrids (Griffing, 1956; Souza Júnior et al., 2010).

The effects of SCA are shown in Table 5, in which the progenitors participating in each cross and the respective effects of SCA are indicated. The estimated effects of GCA show that even if the effects of GCA of the lines are negative for yield, specific combinations can be found that extrapolate that expected in the mean response of the hybrids. For YIELD, it is important to highlight the hybrids coming from crosses between DH170356 × 5702955 (9.645), DH1700402 × CMSM048 (7.485), DH1700358 × CMSM048 (7.435), DH1700358 × CMSM045 (6.295), and DH1700356 × CMSM036 (6.225). However, it is noteworthy that DH170356 × 5702955 (9.645) was the most promising combination, expressing the greatest SCA among all the other crosses, standing out in terms of yield.

The estimates of SCA express the importance of the genes of non-additive effects, which may be understood as the deviations of dominance of the hybrids in relation to what would be expected from them based on the GCA of the progenitors (Sprague & Tatum, 1942; Miranda Filho & Vencovsky, 1999). Thus, it can be affirmed that the hybrids that were identified with much higher SCA values had overall performance different from what was expected. Another question to highlight is that the parent 5702955 was precisely the one of highest GCA value, which shows that even

Table 5. Effects of specific combining hability (SCA) for grain yield tto cross between doubled haploid lines and testers from diferents heterotic groups.

	SCA effects (S_{ij})	
DHs	**Testers**	**Yield**
DH1700402	CMSM035	5,74
DH1700402	CMSM048	7,48
DH1700402	CMSM036	-2,87
DH1700402	5702955	-10,35
DH1700358	CMSM035	6,29
DH1700358	CMSM048	7,43
DH1700358	CMSM036	-3,12
DH1700358	5702955	-10,60
DH1700356	CMSM035	-7,45
DH1700356	CMSM048	-8,41
DH1700356	CMSM036	6,22
DH1700356	5702955	9,64
DH1700388	CMSM035	-2,33
DH1700388	CMSM048	-3,29
DH1700388	CMSM036	-0,15
DH1700388	5702955	5,77
DH1700389	CMSM035	-2,25
DH1700389	CMSM048	-3,21
DH1700389	CMSM036	-0,07
DH1700389	5702955	5,54
SD(Sij)	3,80	
SD(Sij-Sik)	6,21	
SD(Sij-Skj)	6,02	
SD(Sij-Skl)	5,15	

without significant differences among the tester lines for GCA, there are also additive effects involved in this combination.

The DH1700356 and DH1700358 lines used as female progenitors are noteworthy for having been those that most resulted in combinations of high SCA for YIELD. Of the four crosses possible between these lines, two resulted in hybrids of high SCA. In the case of the DH1700356 line, this result corroborates what was expected, this being the progenitor of greatest GCA (Table 5) and that which resulted in the cross with greatest SCA.

In the present study, it should be

DOI: https://doi.org/10.18512/rbms2021v20e1218

considered that a group of hybrids in the initial phase of breeding, derived from doubled haploid lines, was compared to commercial hybrids or hybrids that completed all the stages of a breeding program. The results obtained from the study indicate that DH hybrids are competitive with lines obtained by traditional methods for the characteristics evaluated, and it is possible to select promising genotypes for evaluation in advanced phases of a breeding program.

Conclusions

1 – The agronomic performance of the hybrids derived from doubled haploid lines for grain yield and final stand was lower on average than that observed in hybrids obtained by traditional in this experiment..

2 – The DH1800007 hybrid had grain yield of 13.51 $t.ha^{-1}$, superior to the commercial and experimental control hybrids.

3 – The effects of specific combining ability (SCA) indicated that the combinations DH1700402 × CMSM035, DH1700402 × CMSM048, DH1700358 × CMSM035 × CMSM048, DH1700356 × CMSM036, DH1700356 × 5702955, DH1700388 × 5702955, and DH1700389 × 5702955 were superior among the genotypes evaluated.

4 – The results indicate that hybrids derived from doubled haploid lines not only have advantages such as reduction in the time necessary for obtaining new cultivars but also allow development of hybrids with superior agronomic performance.

Acknowledgments

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Fundação de Apoio à Pesquisa do Estado de Minas Gerais (FAPEMIG), the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes), and Embrapa Milho e Sorgo for support in carrying out this study.

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