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Comparing the efficiency of the three heterotic-group and traditional two heterotic-group classifications for the hybrid maize breeding

Mohammadreza Shiri

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Seed and Plant Improvement Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran.
Email: mohammadrezashiri52@gmail.com

Abstract
Increasing the efficiency of the hybrid-based maize breeding program has highly contributed to the heterotic group classification. The present study was aimed to compare the breeding efficiency of the three heterotic-group (TriHG) classification [Lancaster Sure Crop (LSC), Reid Yellow Dent (RYD), CIMMYT] system and usual two heterotic-group (DiHG) classification (RYD, LSC) system. To accomplish this, specific breeding efficiency (SBE) and general breeding efficiency (GBE) were estimated for the grain yield. The mating design was a line × tester scheme in which seven adapted tropical and subtropical lines were crossed to four testers. GBE increased by 128% in the TriHG classification system as compared to the DiHG system while no significant loss was observed in SBE. It seems that the TriHG system was advantageous over the DiHG system by improving the maize breeding efficiency. Therefore, using one tester from each of the three heterotic groups (RYD, LSC, CIMMYT) could be more efficient in hybrid-based maize breeding programs in temperate regions, including Iran.

Keywords: DiHG; Heterotic group; Heterotic pattern; Line × tester; TriHG

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Introduction

The selection of parents for an elite hybrid is very important in exploiting heterosis. To take advantage of heterosis, knowledge about heterotic grouping and heterotic patterns is required (Melchinger and Gumber 1998). Heterotic group classifications are considered based on origin, pedigree, genetic composition and molecular marker information (Barata and Carena 2006). The success of a maize breeding program depends on the ability to identify and utilize the heterotic groups and patterns efficiently (Richard *et al.* 2018). By choosing parents of hybrids from different heterotic groups, breeders can decrease the chance of blindness in selecting the parents and reduce the chances of evaluating a considerable number of undesirable crosses, while improving the breeding efficiency (Hallauer *et al.* 2010; Fan *et al.* 2014). According to Barata and Carena (2006), proper heterotic grouping assists in maximizing the combining ability and ultimately improving the efficiency of the breeding program. The essential components of the breeding efficiency are the number of released varieties, adoption indicators, selection gain per cycle and cost–benefit analyses. Heterotic grouping increases the chance of identification of feasible commercial hybrids and cost reduction per hybrid (Ceccarelli 2015).

In Iran, the maize germplasm has been classified into four heterotic groups as Lancaster Sure Crop (LSC), Ried Yellow Dent (RYD), Late

Synthetic and the CIMMYT germplasm. LSC × CIMMYT germplasm and RYD × Late Synthetic could be promising heterotic patterns besides the RYD × LSC heterotic pattern (Choukan *et al.* 2006; Shiri 2017; Shiri and Ebrahimi 2017). Li and Wang (2010) reported five heterotic groups, namely Lancaster, the improved Reid (PA), Tangsipingtou (TSPT), Lancaster-like and Tem-tropic I (PB) by reviewing previous works in China. Fan *et al.* (2014) designated CIMMYT germplasm as a new heterotic group to make a three-group classification (TriHG), including RYD, LSC and CIMMYT. They indicated that this system would effectively exploit heterotic patterns for generating adapted hybrids, especially for use in southwestern China. However, prediction by mathematical computations contradicted the results obtained in actual breeding and showed that TriHG should yield lower breeding efficiency than DiHG utilizing the same germplasm (Fan *et al*. 2015). This study was aimed to compare the efficiency of breeding for the TriHG and the DiHG classification systems in Iran.

Material and Methods

Seven desirable tropical and subtropical maize inbred lines which were adapted to climatic conditions of Iran and possessed good agronomic and disease resistance characteristics were selected from the germplasm introduced from CIMMYT. To determine the value of these inbred lines for producing hybrids suitable for the temperate regions of Iran, they were crossed to four testers in a line × tester mating design in 2011. Two of the testers were from LSC, and one from each of RYD and CIMMYT non-temperate heterotic groups (Table 1). The testers were chosen according to the results of the previous experiments (Choukan *et al.* 2006).

The 28 testcrosses were generated in Ardabil Agricultural Research Station, Moghan, Iran (39° 41´ N, 47° 32´ E; 45 m above sea level). Seeds from the female ears (seven inbred lines) were bulked to be used in subsequent testcross evaluations. These testcrosses together with a commercial check, ‘SC705’, were assessed in a randomized complete block design with three replications for two years (2012 and 2013) in Ardabil Agricultural Research Station, Moghan, Iran. Each plot consisted of two rows of 6.48 m length, with a within-row spacing of 18 cm and between-row spacing of 75 cm, which resulted in a population density of ~75000 plants ha^{-1}. To ensure the full seed emergence, two seeds were planted per each planting point. After thinning at the 4-5 leaf stage (about 18 days after planting), only one plant was kept in each planting point. Irrigation, weed control and application of fertilizers were carried out as needed. The amount of fertilizer was determined based on soil tests. For this purpose, 300 kg ammonium phosphate and 100 kg urea were applied before planting and 300 kg urea was also used as the top dressing. The harvesting time was determined by the black-layer formation. Afterward, grain yield was measured at the moisture content of 14%.

Breeding efficiency

Breeding efficiency was measured by two statistics, general breeding efficiency (GBE) and specific breeding efficiency (SBE). GBE measures the efficiency of genetic resource usage, and SBE measures the efficiency of obtaining a maximum output with the utilized inputs.

To compare breeding efficiencies, the number of hybrids having at least 5% higher grain yield than the check for inter-heterotic (RYD × LSC, RYD × CIMMYT, LSC × CIMMYT) and intra-heterotic group (RYD × RYD, LSC × LSC, CIMMYT × CIMMYT) crosses were recorded. The two testers from the LSC heterotic group were designated as T1 and T2, the tester from LSC as T3 and the tester from LSC as T4 (Table 2). Two tester combinations resulted from the TriHG system having one tester from each of the three heterotic groups (tester combinations 1 and 2 in Table 2), while five tester combinations resulted from the two heterotic groups of RYD and LSC for the DiHG system (tester combinations 3 to 7 in Table 2).

For all seven-tester combinations, GBE and SBE were computed as follows (Fan *et al.* 2018):

$$\text{GBE}(\%) = \frac{\text{Number of top} - \text{yielding hybrids among inter} - \text{heterotic crosses in each tester combination}}{\text{Number of top} - \text{yielding hybrids among all crosses}(7 \text{ lines} \times 4 \text{ testers})} \times 100$$

$$\text{SBE } (\%) \text{ (DiHG system)} = \frac{\text{Number of top} - \text{yielding hybrids among inter} - \text{heterotic crosses}}{\text{Total number of inter} - \text{heterotic crosses (made by 7 lines} \times 2 \text{ selected testers)}} \times 100$$

$$\text{SBE } (\%) \text{ (TriHG system)} = \frac{\text{Number of top} - \text{yielding hybrids among inter} - \text{heterotic crosses}}{\text{Total number of inter} - \text{heterotic crosses (made by 7 lines} \times 3 \text{ selected testers)}} \times 100$$

Table 1. The name, pedigree and ecological adaptation of the maize inbred lines under investigation

No.	Code	Pedigree	Ecological type
1	L1	4-CHTSEY,2002/1389/9=1390/13	Mixed tropical/subtropical
2	L2	4-CHTSEY,2002/1389/19=1390/21	Mixed tropical/subtropical
3	L3	7-CHTSEY,2002/1389/33=1390/33	Mixed tropical/subtropical
4	L4	7-CHTSEY,2002/1389/35=1390/37	Mixed tropical/subtropical
5	L5	K18×2-CHTHIY,2002/1389/59=1390/73	Mixed tropical/subtropical
6	L6	K18×2-CHTHIY,2002/1389/59=1390/73	Mixed tropical/subtropical
7	L7	XT03	Mixed tropical/subtropical
8	T1	MO17 (tester)	LSC heterotic group
9	T2	K18 (tester)	LSC heterotic group
10	T3	A679 (tester)	RYD heterotic group
11	T4	K166B(tester)	CIMMYT hetrotic group

Table 2. Classification of tester groups for possible tester combinations from three heterotic groups (TriHG) and two heterotic groups (DiHG); the testers were designated as T1 and T2 (RYD), T3 (LSC) and T4 (CIMMYT).

Classification system	Tester combination	LSC		RYD	CIMMYT
		T1	T2	T3	T4
TriHG	TC1	×	-	×	×
	TC2	-	×	×	×
$DiHG_{(T)}$ †	TC3	×	-	×	-
	TC4	-	×	×	-
$DiHG_{(N)}$ ††	TC5	×	-	-	×
	TC6	-	×	-	×
	TC7	-	-	×	×

†: $DiHG_{(T)}$ system of two heterotic groups, with one tester from each of the two traditional heterotic groups (LSC, RYD); ††: $DiHG_{(N)}$ system of two heterotic groups, one from the traditional heterotic groups (LSC, RYD) and the other one from the new heterotic groups.

Heterotic classification of the inbred lines

The seven inbred lines were classified into different heterotic groups based on the specific combining ability and grain yield of a cross (Fan *et al*. 2018). If the grain yield of the crosses between a line and the selected testers was the lowest and the specific combining ability (SCA) was either not statistically significant and negative or significant and negative, this line was assigned to the same heterotic group as the tester. Mean grain yield and SCA of the crosses among the selected testers from each of the seven tester combinations and seven lines were calculated for classifying the lines into two or three heterotic groups (DiHG and TriHG systems).

Statistical analyses

The general combining ability (GCA) for lines and testers and SCA for crosses were calculated based on the line × tester mating design (Kempthorne 1970) that has been frequently used in various studies (e.g. Abadi *et al*. 2011; Tabrizi *et al*. 2012). The line × tester analysis was performed utilizing the AGD-R (Analysis of Genetic Designs in R) package. The differences in breeding efficiencies between the DiHG and TRiHG systems were evaluated by the *t*-test method.

Results and Discussion

The combined analysis of variance for grain yield revealed that mean squares for crosses, testers, lines and line × tester, crosses × year and tester × year interactions were significant but the line ×

year and tester × line× year interactions were not significant.

Grain yields of crosses were shown in Table 3. Among 28 possible crosses, 13 crosses with a grain yield of at least 5% higher than the check hybrid (9.26 tons per hectare) were identified. Six of these 13 top-yielding crosses were related to the tester K166B. The highest grain yield was obtained from crossing the lines L2 and L5 with the tester K166B. The inbred line K166B has been derived from the non-temperate CIMMYT population (Choukan *et al.* 2006). Thus, to identify hybrids with high yield potential, the use of three testers (one tester from each of the three established maize heterotic groups) is recommended to improve the breeding efficiency of temperate-maize breeding programs of Iran, especially in the early breeding stages.

GBE and SBE of the seven tester combinations were presented in Table 4. Top-yielding crosses for the inter-heterotic and intra-heterotic groups in each of the seven tester combinations are shown in the boldface. Nine of the 13 high-yielding crosses (Table 3) among the total 28 crosses corresponded to the tester combination 1 (TriHG; MO17, A679, K166B). Only one of the top-yielding crosses in the tester combination 1 belonged to the intra-heterotic group (L5 × MO17) and the rest of the top-yielding crosses (eight of nine) belonged to the inter-heterotic groups (Table 5).

Table 6 shows the results of mean SCA effects in the inter-heterotic and intra-heterotic crosses of the DiHG and TriHG systems. The differences between TriHG and DiHG for mean grain yield and mean SCA were not significant (Table 6). Considering overall averages of the top-yielding and low-yielding data showed that in spite of the considerable differences (t= 3.517, α= 0.002) between mean SCA effects in the inter-heterotic (SCA= 0.157) and the intra-heterotic (SCA= -0.159) crosses, no significant differences (t= 2.45, α= 0.06) were observed between inter-heterotic crosses (with 10.30 t/ha^{-1}) and intra-heterotic crosses (with 10.05 t ha^{-1}) for grain yield in the high-yielding group. These results were in concordance with the finding of Fan *et al.* (2018).

Table 3. Grain yield (tons.ha^{-1}) of 28 crosses of maize (7 lines × 4 testers).

Rank	Line	MO17	%SH	Line	K18	%SH	Line	A679	%SH	Line	K166B	%SH
1	**L3**	**10.25†**	**10.67**	**L3**	**10.24**	**10.56**	**L7**	**10.59**	**14.41**	**L2**	**10.61**	**14.62**
2	**L5**	**10.17**	**9.84**	**L2**	**10.17**	**9.77**	**L5**	**10.43**	**12.61**	**L7**	**10.52**	**13.64**
3	L6	8.92	-3.69	**L4**	**9.95**	**7.44**	L6	9.43	1.85	**L5**	**10.25**	**10.68**
4	L7	8.53	-7.86	**L7**	**9.75**	**5.34**	L1	9.42	1.78	**L3**	**10.03**	**8.34**
5	L2	8.36	-9.75	L1	9.22	-0.45	L2	9.28	0.24	**L4**	**9.74**	**5.21**
6	L1	8.09	-12.64	L5	8.92	-3.62	L3	9.09	-1.80	L1	9.55	3.08
7	L4	8.08	-12.75	L6	8.45	-8.80	L4	9.07	-2.02	L6	9.26	0.02

†: Top-yielding crosses with the grain yield 5% higher than the check (9.34 ton per hectare), i.e. the % standard heterosis (%SH) > 5% are shown in boldface.

Table 4. Heterotic groups for each of the seven maize lines in different tester combinations based on specific combining ability and grain yield.

Tester combinations	TC1			TC2			TC3		TC4		TC5		TC6		TC7	
	MO17†	A679	K166B	K18	A679	K166B	MO17	A679	K18	A679	MO17	K166B	K18	K166B	A679	K166B
L1	×	-	-	×	-	-	×	-	×	-	×	-	×	-	×	-
L2	×	-	-	-	×	-	×	-	-	×	×	-	×	-	×	-
L3	-	×	-	-	×	-	-	×	-	×	-	×	-	×	×	-
L4	×	-	-	-	×	-	×	-	-	×	×	-	-	×	×	-
L5	×	-	-	×	-	-	×	-	×	-	×	-	×	-	×	-
L6	×	-	-	×	-	-	×	-	×	-	×	-	×	-	-	×
L7	×	-	-	×	-	-	×	-	×	-	×	-	×	-	-	×

†: Testers MO17 and K18 belonged to the RYD heterotic group while A679 and K166B belonged to the LSC and CIMMYT heterotic groups, respectively.

Table 5. Breeding efficiencies for possible combinations of testers of the two heterotic-group (DiHG) and three heterotic-group (TriHG) classification systems, based on numbers of crosses with grain yield 5% higher than that of the check (9.34 ton per hectare).

System	Tester combination	Inter-group	Intra-group	Total	GBE	SBE
TriHG	TC1	8	1	9	0.62	0.57
	TC2	10	1	11	0.77	0.71
	Mean	-	-	10	0.695	0.64
$DiHG_{(T)}$ ‡	TC3	3	1	4	0.23	0.43
	TC4	5	1	6	0.38	0.71
	Mean	-	-	5	0.305	0.57
$DiHG_{(N)}$†	TC5	5	2	7	0.38	0.71
	TC6	5	4	9	0.38	0.71
	TC7	5	2	7	0.38	0.71
	Mean	-	-	6.6	0.38	0.71

‡: $DiHG_{(T)}$ system with one tester from each of the two traditional heterotic groups (LSC and RYD); †: $DiHG_{(N)}$ system, two-heterotic groups [one from the traditional heterotic group (LSC and RYD) and the other from the new heterotic group].

Table 6. Mean grain yield (Avg-GY) and mean specific combining ability (Avg-SCA) for inter-heterotic crosses (inter-cross) and intra-heterotic crosses (intra-cross) between the top-yielding group and the low-yielding group.

System	Tester combination	Top-yielding group (GY > 5% of the check)				Lowest-yielding group (GY ≤ 5% of the check)			
		Inter-cross		Intra-cross		Inter-cross		Intra-cross	
		Avg-GY	Avg-SCA	Avg-GY	Avg-SCA	Avg-GY	Avg-SCA	Avg-GY	Avg-SCA
TriHG	TC1	10.30	0.26	10.17	0.48	9.34	-0.04	8.51	-0.39
	TC2	10.25	0.22	9.75	-0.35	9.42	-0.09	9.01	-0.25
	Mean	10.28	0.24	9.96	0.065	9.38	-0.065	8.76	-0.32
$DiHG_{(T)}$ ‡	TC3	10.42	0.46	10.17	0.22	9.30	0.12	8.51	-0.35
	TC4	10.27	0.53	9.75	-0.37	9.43	0.25	9.01	-0.47
	Mean	10.35	0.495	9.96	-0.075	9.365	0.185	8.76	-0.41
P-value for comparing TriHG with DiHG(T)		0.52	0.41	1.00	0.81	0.87	0.13	1.00	0.43
$DiHG_{(N)}$ †	TC5	10.28	0.30	10.10	-0.07	9.40	-0.09	8.40	-0.23
	TC6	10.31	0.25	9.92	-0.20	9.40	0.05	8.86	-0.18
	TC7	10.25	0.17	10.48	0.03	9.40	-0.20	9.26	-0.10
	Mean	10.28	0.24	10.17	-0.08	9.40	-0.08	8.84	-0.17
P-value for comparing TriHG with DiHG(T)		0.87	1.00	0.49	0.79	0.70	0.88	0.84	0.13
	Grand mean	10.30	0.31	10.05	-0.04	9.38	0.00	8.79	-0.28

‡: $DiHG_{(T)}$ system with one tester from each of the two traditional heterotic groups (LSC and RYD); †: $DiHG_{(N)}$ system, two heterotic groups [one from the traditional heterotic groups (LSC and RYD) and the other from the new heterotic group].

Conclusions

In this study, the breeding efficiency of the TriHG system was compared with the DiHG system. We recommend the use of the TriHG system in maize breeding programs in Iran because the TriHG system improves breeding efficiency as compared with the DiHG system. Therefore, these results lead to re-thinking about the breeding strategy in Iran for improving the breeding efficiency by using the TriHG system. In the breeding program, by including tester K166B from the CIMMYT heterotic group, the classification of CIMMYT-derived lines could be done more efficiently than when they are classified by RYD and LSC.

Conflict of Interest

The authors declare that they have no conflict of interest with any people or organization concerning the subject of the manuscript.

References

Abadi JM, Khavari KS, Syah SB, Movafegh S and Golbashy M, 2011. Estimation of combining ability and gene effects in forage maize (*Zea mays* L.) using line × tester crosses. Journal of Plant Physiology and Breeding 1: 57-67.

Barata C and Carena MJ, 2006. Classification of North Dakota maize inbred lines into heterotic groups based on molecular and testcross data. Euphytica 151: 339-349.

Ceccarelli S, 2015. Efficiency of plant breeding. Crop Science 55: 87-97.

Choukan R, Hossainzadeh A, Ghannadha MR, Warburton ML, Talei AR and Mohammadi SA, 2006. Use of SSR data to determine relationships and potential heterotic groupings within medium to late maturing Iranian maize inbred lines. Field Crops Research 95: 212-222.

Duvick DN, 2001. Biotechnology in the 1930s: the development of hybrid maize. Nature Reviews Genetics 2: 69-74.

Fan X-M, Bi YQ, Zhang YD, Jeffers DP, Yao WH, Chen HM, Zhao LQ and Kang MS, 2015. Use of the Suwan1 heterotic group in maize breeding programs in southwestern China. Agronomy Journal 107: 2353-2362.

Fan X, Bi Y, Zhang Y, Jeffers D, Yin X and Kang M, 2018. Improving breeding efficiency of a hybrid maize breeding program using a three heterotic-group classification. Agronomy Journal 110: 1209-1216.

Fan XM, Zhang YD, Yao WH, Bi YQ, Liu L, Chen HM and Kang MS, 2014. Reciprocal diallel crosses impact combining ability, variance estimation, and heterotic group classification. Crop Science 54: 89-97.

Hallauer AR, Carena MJ and Miranda de Filho JB, 2010. Quantitative Genetics in Maize Breeding. Sixth edition. Springer Science+Business Media, New York, USA, 680 pages.

Kempthorne O, 1970. An Introduction to Genetic Statistics. Wiley, USA, 545 pages.

Li Y and Wang TY, 2010. Germplasm base of maize breeding in China and formation of foundation parents. Journal of Maize Sciences 18: 1–8.

Melchinger AE and Gumber RK, 1998. Overview of heterosis and heterotic groups in agronomic crops. In: Lamkey KR and Staub JE (eds.) Concepts and Breeding of Heterosis in Crop Plants. Volume 25. Pp. 29-44. CSSA Special Publications, USA.

Richard C, Osiru DS, Mwala MS and Lubberstedt T, 2018. Genetic diversity and heterotic grouping of the core set of southern African and temperate maize (*Zea mays* L.) inbred lines using SNP markers. Maydica 61: 1- 9.

Shiri M, 2017. The performance of temperate maize testers for screening of tropical and subtropical germplasm. Journal of Crop Breeding 9: 85-94 (In Persian with English abstract).

Shiri M and Ebrahimi L, 2017. The selection of maize lines derived from CIMMYT germplasm through

combining ability with temperate testers. Cereal Research 7: 101-114 (In Persian with English abstract).
Tabrizi M, Hassanzadeh F, Moghaddam M, Alavikia S, Aharizad S and Ghaffari M, 2012. Combining ability and gene action in sunflower using line * tester method. Journal of Plant Physiology and Breeding 2: 35-44.

مقایسه بازده سیستم سه گروه-هتروتیکی (TriHG) و دو گروه-هتروتیکی سنتی (DiHG) برای اصلاح هیبرید ذرت

محمدرضا شیری

مؤسسه تحقیقات اصلاح و تهیه نهال و بذر، سازمان تحقیقات، آموزش و ترویج کشاورزی، کرج
Email: mohammadrezashiri52@gmail.com

چکیده

تعیین گروه هتروتیک لاین‌های ذرت کمک زیادی به افزایش کارآیی برنامه‌های اصلاح ذرت مبتنی بر تولید هیبرید کرده است. بنابراین، مطالعه حاضر با هدف مقایسه کارآیی برنامه اصلاح ذرت با سیستم سه گروه-هتروتیکی (TriHG) شامل گروه‌های هتروتیک Lancaster Sure Crop (LSC)، Reid Yellow Dent (RYD) و CIMMYT و سیستم دو گروه-هتروتیکی سنتی (DiHG) شامل گروه‌های هتروتیک RYD وLSC، انجام گرفت. برای دستیابی به این هدف، بازده خصوصی برنامه اصلاحی (SBE) و بازده عمومی برنامه اصلاحی(GBE) برای عملکرد دانه برآورد شدند. هفت لاین سازگار با منشاء نواحی گرمسیری و نیمه‌گرمسیری با چهار تستر در قالب طرح تلاقی لاین × تستر تلاقی داده شدند. سیستم TriHG در مقایسه با سیستم DiHG بازده خصوصی برنامه اصلاحی را بدون کاهش محسوس در بازده عمومی، ۲۸ درصد افزایش داد. به نظر می‌رسد که در برنامه اصلاح ذرت مبتنی بر تولید هیبرید، استفاده از سه تستر با یک تستر از هر یک از گروه‌های هتروتیک RYD، LSC وCIMMYT در مناطق معتدل کارآمدتر از سیستم DiHG باشد. لذا توصیه می‌گردد جهت افزایش کارآیی برنامه‌های اصلاح ذرت در کشور، از سیستم TriHG استفاده شود.

واژه‌های کلیدی: الگوی هتروتیکی؛ گروه هتروتیکی؛ لاین × تستر؛ DiHG؛ TriHG