Heterotic and heritability pattern of grain yield and related traits in doubled haploid f1 hybrids of maize (*Zea mays* L.)

Khunsa Khakwani[1]*, Rahime Cengiz[2], Muhammad Asif[1], Muhammad Ahsan[1].
1 Department of Plant breeding and genetics, University of Agriculture, Faisalabad 38040, Pakistan
2 Maize Research Institute, Sakarya-54000, Turkey

* Corresponding author: E-mail: khunsakhakwanioops@gmail.com

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Abstract

In this study, fifteen cross combinations evolved from five doubled haploid maize lines, and three open-pollinated varieties used as testers were evaluated for broad-sense heritability, narrow-sense heritability, heterosis, and heterobeltiosis values during 2017-18. The broad-sense heritability and narrow-sense heritability recorded higher for all the studied traits. Higher broad-sense heritability was recorded for grains per cob (99.6%), grain yield per plant (98.8%), cob length (98.2%), and kernels per cob row (98.1%). Higher narrow-sense heritability was found in grain yield per plant (87.7%), cob height (79.8%), kernel per cob row (79.5%), cob diameter (68.7%) and grains per cob (66.1%). Most of the crosses exhibited very high values of heterosis and heterobeltiosis and ranged from -0.01 to 37.3 % percent for grain yield. The F1 hybrids, L1×T1, L1×T2, L1×T3, L2×T2, L4×T1, L4×T2, L5×T1, L5×T2, L5×T3, L2×T3, L3×T3, and L5×T3 were shown to be the best with very good heterosis and heterobeltiosis values for most of the grain yield-related traits. Heterosis and heritability analysis indicated that these doubled haploid lines evolved from a very narrow genetic source (single cross F1 hybrid) showed a great potential toward improvement in grain yield and its related traits. It is recommended that instead of crossing them with low yielding open-pollinated varieties as testers these lines must be crossed in diallel mating designfor further revealing their potential toward grain yield and its related traits.

Introduction

Maize (*Zea mays* L.) is a C4 plant and can utilize solar energy more efficiently than any other cereals. This crop can be utilized for multiple purposes like human food, poultry feed, animal fodder, and industrial raw material. Its importance has been rapidly growing in recent years in Asia, where 4% annual growth recorded as compared to other cereals. In Asia, maize consumption (77%) is rising faster than yield (38%), (Prasanna, 2014). To meet the global demand of maize we need to double its production by 2050. To sustainably meet the fast-rising demand for maize, genetic gain per unit time needs to be significantly enhanced. Traditional maize inbred line development requires 6-10 seasons of self-breeding, i.e., 3-5 years if two seasons in a year are utilized (Hallauer et al., 2010). Therefore, doubled haploid (DH) technology is a perfect approach to accelerate varietal development. The efficiency of maize breeding programs will be significantly enhanced if superior crosses could be predicted before field evaluation based on the screening of parental inbred lines. The knowledge of different heritability patternshelps to sketch out selection in a breeding population. Heritability study is of vital importance, as it will determine the choice of breeding procedures for selection.

Heritability is usually exploited to decide the breeding method and to predict selection gain(Ilker et al., 2009). The characters with high narrow-sense heritability are under additive genetic effect and they can easily be fixed with simple selections that result in very quick progress (Noor et al., 2017).

During the last 100 years, plant breeders have been working on heterosis and it is still their focus. It has been used in the production and breeding of many crop species (Melchinger and Gumber, 1998). Different hypothesis made by scientists and plant breeders are summarized (Table 1)

The objective of this study is to evaluate newly developed doubled haploid (DH) lines from a single donor source for their heterotic pattern, narrow and broad-sense heritability, to identify better-performing parents for future hybrid-breeding program. The findings of this study will be useful in predicting the efficiency of doubled haploid (DH) lines to accelerate hybrid maize developmental programs.

Table 1 -Scientific views and references regarding heterosis in plant breeding history

Scientific views	References
(The dominance hypothesis) After crossing the combination of different dominant alleles, contributed by each parent results in the increase of vigor.	(Bruce, 1910; Keeble and Pellew, 1910)
(The heterozygosis theory) The combination of the heterozygotes of different alleles increases vigor.	(Shull, 1911; East and Hayes, 1912; East, 1936)
(Overdominance) Heterotic gene interaction.	(Hull, 1945)
The nature of the inter-allelic interaction may work similarly to dominant complementary factors.	(Brieger, 1930)
The quantitative gene interaction produces heterosis.	(Rasmusson, 1933)
"Andropogoneae" a wild ancestor of maize already possessed the heterotic gene system.	(Collins, 1918)
Recessive lethal has become established as balanced lethal in inter-specific hybrid but incompatible when homozygous.	(Brieger, 1944)
Maize is an excellent model species for the study and application of heterosis.	(Flint-Garcia et al., 2005; Troyer, 2006)
The basic mechanism that results in heterosis is still unclear.	(Coors and Pandey, 1999)
Heterosis is a result of the variation that is present within a species. In maize a surprisingly high level of allelic variation is documented which is generated by transposons and repetitive DNA. In a hybrid, more comprehensive and novel allelic interactions may be the reason for heterosis.	(Nathan and Stupar, 2007)
In maize heterosis increases yields by 15% per annum.	(Duvick, 1999)

Material and methods

Field trials and maize genotypes

The present study carried out in the field research area of the Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan during the spring and summer seasons of the years 2016 and 2017. The maize genetic material was comprised of eight parents and their fifteen F1 hybrids. The five doubled haploid (DH) lines developed through a single donor source (F1 hybrids, FH-949) were crossed with three OPVs (open-pollinated varieties) taken at random as testers using Line × tester mating design. The seed of the three OPVs namely Agati-2002, EV-5098, and EV-3001 collected from Ayub Agriculture Research Institute, Faisalabad, Pakistan. The five parental doubled haploid (DH) lines were crossed with the three open pollinated verities (OPVs) as testers during the spring season of the year 2016. In the next year during the same spring season five parental lines and three testers along with their fifteen cross combinations were sown in the field under randomized complete block design (RCBD) with three replications.

Agronomical trait evaluation

The heterosis and heterobeltiosis values for the cross combinations were also computed (Falconer and Mackay, 1996). The values of the broad-sense heritability (Falconer and Mackay, 1996) and narrow-sense heritability using offspring-parent regression (Falconer, 1989) also computed. The whole experiment carried out under field conditions with 25 cm plant-to-plant and 75 cm row-to-row distance. The data of ten plants from each replication of plant height (cm), cob height (cm), cob length (cm), ear diameter (cm), kernel rows per cob, kernels per ear row, grains per plant, 100-grain weight (g) and grain yield per plant (g) recorded.

Data analysis

The recorded data analysed using analysis of variance (Steel et al., 1997). The data collected for all the nine parameters was also statistically analysed for the heterosis study. The values of mid parent, better parent, heterosis and heterobeltiosis were computed (Falconer and Mackay, 1996).

Parent heterosis over mid parent

(MP) = $100 \times (F_1 - MP) / MP$

Parent heterosis over better parent

(BP) = $100 \times (F_1 - BP) / BP$

MP = [Female parent (♀) + Male parent (♂)] / 2

BP is mean of better parents

A t-test was applied (Wynne et al., 1970) to test the significance of heterosis over mid and better parents' as

$t_{(static)} = (F1\text{-}MP) / (3/8\, \delta^2\, E)^{1/2}$

$t_{(static)} = (F1\text{-}BP) / (1/2\, \delta^2\, E)^{1/2}$

Table 2 - Heterosis and heterobeltiosis for grain yield and its related traits of maize

Crosses	Grain yield/plant		Plant height		cob height		cob length		cob height		kernel rows/cob		kernels per cob		100-grain weight		grains per plant	
	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis	Mid parent heterosis	Heterobeltiosis
L1×T1	-27.4**	-5.53**	4.5**	3.9**	11.3**	4.7**	-2.79**	-1.03**	6.76**	2.23**	7.32**	1.91 ns	-0.67**	-0.13**	-0.46**	-0.09**	-18.7**	-7.4**
L1×T2	-23.4**	-4.49**	2.3**	2.0**	-0.4**	-0.2**	3.89**	1.45**	-1.04**	-0.35**	15.0**	3.82 ns	-13.95**	-3.00**	4.80**	0.98**	-19.2**	-7.4**
L1×T3	-8.48**	-1.55**	5.6**	4.7**	1.9**	0.9**	4.99**	1.78**	5.71**	1.88**	2.44**	0.63**	-3.79**	-0.75**	3.51**	0.74**	-8.86**	-3.1**
L2×T1	-0.01**	-0.003**	12.3**	9.3**	9.4**	3.2**	11.92**	3.84**	-9.09**	-3.17**	17.07**	4.46 ns	10.00**	2.00**	-8.75**	-1.97**	16.2**	6.2**
L2×T2	15.6**	3.02**	7.4**	5.7**	-2.6**	-1.0**	7.36**	2.39**	-12.13**	-4.34**	20.00**	5.09**	0.55**	0.13**	3.50**	0.78 ns	17.7**	6.6**
L2×T3	37.3**	6.84**	17.2**	12.7**	0.6**	0.2**	14.24**	4.39**	-8.78**	-3.05**	17.07**	4.46 ns	11.24**	2.38**	8.62 ns	1.97 ns	34.6**	11.8**
L3×T1	13.6**	2.59**	0.4**	0.3**	5.5**	1.8**	1.52**	0.51**	-11.03**	-3.52**	-4.55**	-1.28**	10.64**	2.50**	-1.36**	-0.29**	29.7**	10.7**
L3×T2	19.5**	3.52**	0.6**	0.5**	1.2**	0.4**	3.29**	1.12**	-10.00**	-3.29**	-2.33**	-0.64 ns	-3.32**	-0.88**	0.81**	0.17**	32.4**	11.4**
L3×T3	35.7**	6.09**	4.2**	3.3**	5.4**	1.9**	7.60**	2.48**	-9.96**	-3.17**	-4.55**	-1.28**	8.63**	2.13**	3.44**	0.74**	48.6**	15.4**
L4×T1	-26.8**	-5.99**	3.8**	2.9 **	8.5**	2.9**	14.44**	5.09**	-1.14**	-0.35**	2.44**	0.64**	27.61**	5.63**	-5.31**	-1.32 ns	3.83**	1.58**
L4×T2	-9.4**	-2.01**	1.3**	1.0**	3.4**	1.3**	15.53**	5.52**	-6.27**	-1.99**	5.00**	1.28 ns	11.83**	2.75**	-9.31**	-2.27**	6.65**	2.67**
L4×T3	4.76**	0.97**	7.9**	5.9**	-3.2**	-1.2**	17.47**	5.94**	3.82**	1.17**	2.44**	0.64**	25.58**	5.51**	-10.0**	-2.51**	17.0**	6.26**
L5×T1	-4.74**	-0.96**	6.7**	5.7**	15.8**	5.3**	1.49**	0.51**	-2.31**	-0.82**	2.44**	0.64**	25.00**	5.01**	-1.09**	-0.24**	4.05**	1.58**
L5×T2	-1.78**	-0.34**	4.9**	4.4**	6.9**	2.6**	4.31**	1.49**	-6.12**	-2.23**	5.00**	1.28 ns	4.92**	1.13**	-0.56**	-0.12**	5.94**	2.25**
L5×T3	2.76**	0.51**	10.7**	8.9 ns	3.9**	1.5**	8.88**	2.95**	-1.32**	-0.47**	2.44**	0.64**	13.61**	2.88**	-5.38**	-1.19**	17.9**	6.16**

** = Significant at 5% probability level, ns = non-significant
L1=Parental doubled haploid DH-Line1, L2=Parental doubled haploid DH-Line2, L3=Parental doubled haploid DH-Line3, L4=Parental doubled haploid DH-Line4, L5=Parental doubled haploid DH-Line5

Coefficients of variability

The means, standard error and coefficients of variability of each character were calculated.

CV (%) = (SD/) × 100

Where

CV = Coefficient of variability (%)

SD = Standard deviation

$\bar{X}$ = grand mean for the trait

Genotypic coefficient of variance was determined by:

$$GCV= [(\sqrt{\delta^2_g}/\bar{X}] \times 100$$

and

Phenotypic coefficient of variability was determined by:

PCV = [√δ2P/$\bar{X}$] × 100

Where

δ2g = Genotypic variance

δ2p = Phenotypic variance

Results and discussion

Heterotic pattern

Significant mid parent heterosis and heterobeltiosiswas reported for most of the F1 crosses for grain yield and its related traits (Table 2). Better parent heterosis or heterobeltiosis was significant for almost all F1 hybrids except for the cross combination L5×T3 which showed the non-significant result.

Plant height

The higher heterobeltiosis was recorded for the F1 hybrids, L2×T1, L2×T3, and L5×T1 for plant height. The higher plant height indicated that the respective hybrids may be used for fodder production (Ayub et al., 2002). The negative heterosis and heterobeltiosis indicate the decrease in the trait may occur in the next generation; therefore, the selection may be made to fix decrease in specific trait for the indirect improvement of crop plant yield and productivity (Ali et al., 2013; Ali et al., 2014;Appunu and Satyanarayana., 2007; Devi et al., 2007; Frascaroli et al., 2007).

Cob height

For the cob height significant and positive heterosis and heterobeltiosis was recorded for all of the F1 hybrids except for 3 cross combinations (L1×T2, L2×T2, and L4×T3) which showed negative and significant values. The parents of these F1 hybrids (L1×T2, L2×T2, and L4×T3) may be used for the development of plants with low bearing cobs. The negative heterobeltiosis indicated that the cob height in next-generation may be lower;it is a recommended trait for the good performance of the hybrids. The cob height is an important trait to develop lodging resistant and more yielding maize hybrids (Zsubori et al., 2019). The maize plant bearing cobs at lower internodes are usually resistant to lodging and can tolerate higher plant body/cobs weights (Muraya et al., 2006; Ji et al., 2006; Devi et al., 2007).

Cob length

The positive and significant herterosis and heterobeltiosis values for cob length for all F1 hybrids were recorded except for the cross combination L1×T1 that showed significant but negative heterosis. The F1 hybrids, L2×T3, L4×T1, L4×T2, and L4×T3 were found to be the best F1 hybrids for cob length of maize. The cob length determined grain yield per plant and plays an important role in improving grain yield and production of maize. The selection based on cob length may be fruitful to improve grain production (Khan et al., 2008; Ali et al., 2014; Amanullah et al., 2011; Muraya et al., 2006; Solomon et al., 2012).

Cob diameter

The significant and positive heterosis and heterobeltiosis for cob diameter were recorded for 3 out of 15 F1 hybrids (L1×T1, L1×T3, and L4×T3). The higher cob diameter indicated that the grain to stover ratio may be higher. If the grain size is high then selection can be made based on cob diameter to improve grain yield in maize (Manivannan, 1998; Yang et al., 2005; Troyer, 2006; Kanagarasu et al., 2010).

Kernel rows per cob

The better parent heterosis for kernel rows per cob was found significant and positive for 6 out of 15 hybrids (L1×T3, L2×T2, L4×T1, L4×T3, L5×T1, and L5×T3). The highest value of heterobeltiosis for the trait kernel row per cob was found for the F1 hybrids L2×T2. Various researchers and maize breeders have suggested grain rows per cob as the main selection criterion (Meghji et al., 1984; Tollenaar et al., 2004; Duvick, 2005).

Kernels per cob row

The significant and positive heterosis and heterobeltiosis were found for kernels per cob row for 11 cross combinations (L2×T1, L2×T2, L2×T3, L3×T1, L3×T3, L4×T1, L4×T2, L4×T3, L5×T1, L5×T2 and L5×T3). A large number of grains per cob row indicated that the cob length might be higher due to which the number of grains per cob and grain yield per plant may also be higher (Manivannan, 1998; Devi and Muhammad, 2001). This indicated that these F1 hybrids may be used for the improvement of grain yield in maize(Kutlu and Sirel,

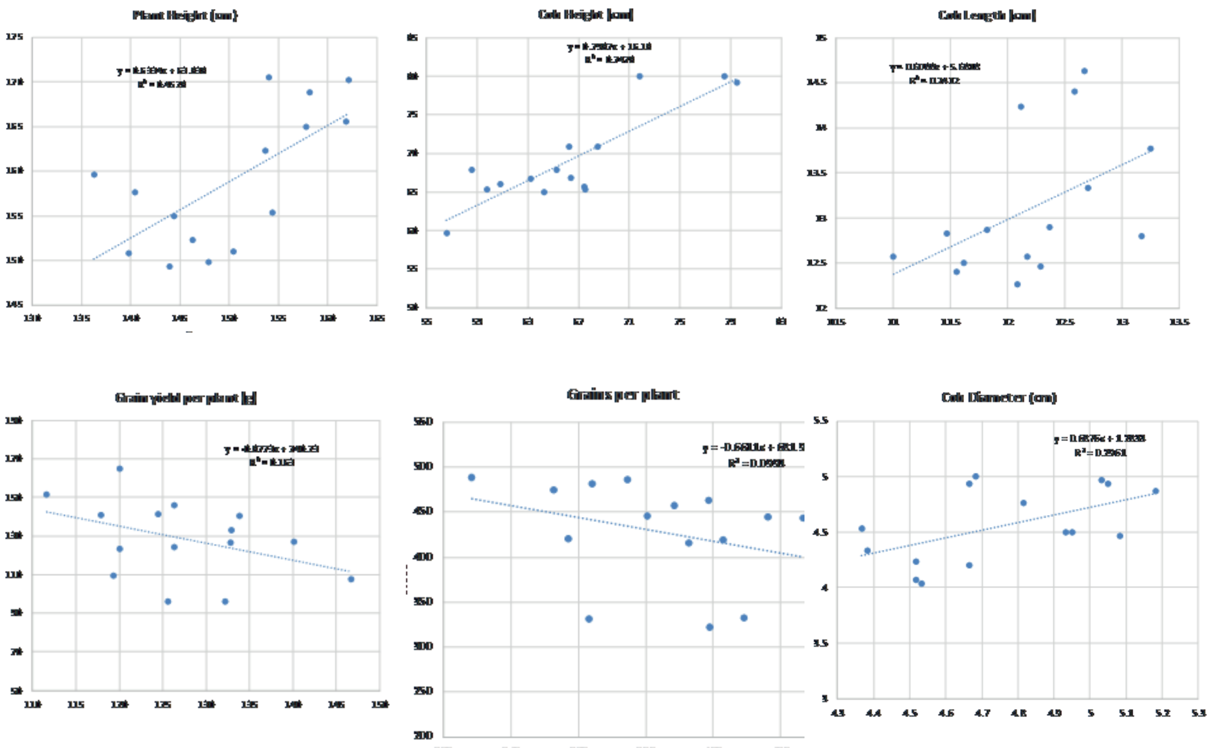

Fig. 1 - Graphical representation of narrow-sense heritability (h2NS) of grain yield and related traits using offspring-parent regression Parental values of the grain yield and related traits are taken at the X-axis and values of the offspring for the same traits are taken at the Y-axis.

2019; Tollenaar et al., 2004; Yang et al., 2005; Alam et al., 2008).

100-grain weight

The F1 hybrids, L1×T3, L3×T2, and L3×T3 were found to be the best F1 hybrids for the 100-grain weight of maize. The hybrids with higher 100-grain yield indicated that the grain size may be higher or bold seeds will be produced which leads to improving grain yield per plant (Shah et al., 2009).

Grains per plant

The F1 hybrids, L1×T1, L1×T2, L1×T3, L2×T2, L4×T1, L4×T2, L5×T1, L5×T2 and L5×T3 were found to the best F1 hybrids for grains per plant of maize. The selection based on grains per plant may be helpful to develop higher yielding maize hybrids (Khodarahmpour and Hamidi, 2012; Konak et al., 2015;Sekip et al., July 2011; Tollenaar et al., 2004).

Grain yield per plant

The F1 hybrids, L2×T2, L2×T3, L3×T1, L3×T2, and L3×T3 were found to be the best for grain yield per plant. The highest grain yield per plant may be used as main selection criteria to develop higher-yielding maize hybrids for better crop production and productivity (Katana et al., 2005; Makumbi et al., 2005; Revilla et al., 2006; Meseka et al., 2006; Guimaraes et al., 2007; Ojo et al., 2007; Geeta et al., 2001; Kara, 2001; Dickert and Tracy, 2002; Malik et al., 2004; Bajaj et al., 2007; Amiruzzaman et al., 2011; Ikramullah et al., 2011; Jain and Bharadwaj, 2014).

Heritability pattern

The broad-sense heritability and narrow-sense heritability was recorded higher for most of the traits studied. The traits plant height, cob height, cob length, cob diameter, kernels per cob row, kernel rows per cob, grain per plant and grain yield per plant were highly controlled by the additive type of gene action. The range of broad-sense heritability for the different traits understudy was recorded from 81.5% to 99.6%(Table 3). Higher heritability was found for grains per cob (99.6%) followed by plant height (99.1%), grain yield per plant (98.8%), cob height (98.3%), cob length (98.2%) and kernels/grains per cob row (98.1%). The result of the narrow sense heritability (Table 3)for plant heightwas found high (63.3%),for cob height (79.8%), (60.8) for cob length, (68.7%) for cob diameter, (77%) for the trait kernel rows per cob, (79.5%) for kernels per cob row, (66.1%) for grains per plant and (87.7%) for grain yield per plant. The classification of heritability stands low when it is 50 percent (Stansfield, 1991). Some stu-

Table 3 -Genetic components for grain yield and its related traits

Parameter		VAR (G)	VAR (P)	VAR (E)	h2BS	h2NS
		350.442	353.527	3.085	99.1 %	63.3%
Plant Height (cm)	1	GCV	PCV	ECV		
		12.181	12.235	1.143		
		154.438	157.118	2.681		
Cob Height (cm)	2	GCV	PCV	ECV	98.3 %	79.8%
		18.623	18.784	2.454		
		6.125	6.238	0.113		
Cob Length (cm)	3	GCV	PCV	ECV	98.2 %	60.8%
		19.861	20.043	2.697		
		0.274	0.292	0.018		
Cob Diameter (cm)	4	GCV	PCV	ECV	93.9 %	68.7%
		11.469	11.837	2.932		
		1.291	1.534	0.243		
Kernels Rows Per ear	5	GCV	PCV	ECV	84.1 %	77%
		8.031	8.755	3.486		
		83.301	84.877	1.576		
Kernels per ear row	6	GCV	PCV	ECV	98.1 %	79.5%
		30.916	31.207	4.252		
		25370.7	25466.1	95.481		
Grains per plant	7	GCV	PCV	ECV	99.6 %	66.1%
		40.680	40.756	2.496		
		7.423	9.151	1.728		
100 grain weight (g)	8	GCV	PCV	ECV	81.1 %	42.8%
		8.961	9.950	4.324		
		3040.454	3078.501	38.046		
Grain yield per plant (g)	9	GCV	PCV	ECV	98.8 %	87.7%
		45.773	46.059	5.120		

VAR (G)= genotypic variance, VAR (P)= phenotypic variance, VAR (E)= environmental variance,
h2BS= broadsense heritability, h2NS= narrosense heritability, GCV= genotypic cofficient of variance,
PCV= phenotypic cofficient of variance, ECV= environmental cofficient of variance

dies have reported high, narrow-sense heritability at 73 percent (Wannows et al., 2010) and moderate at 40.65 percent for yield (Hefny, 2007). High narrow sense heritability indicated that the contribution of the additive variance effect was greater in the inheritance of these characters(Woodhouse et al., 2006; Buckler et al., 2009; Peiffer et al., 2013). A selection of early generations is more effective to develop these characters, and huge progress in selection can be obtained if the selection is conducted on that character(Aditya et al.,2010; Aly et al., 2011; Bhavana et al., 2011; Sumalini, 2012; Rajitha, 2013). Various researchers suggested narrow sense heritability as selection criteria for the development of synthetic crop varieties (Ashrai and Mc-Nelly, 1990; Sujiprihati et al., 2003; Khan et al., 2014). The narrow-sense heritability (42.8%) was found lower for the trait 100-grain weight. This showed the presence of the dominant type of gene action(Yadav et al., 2002; Rafique et al., 2004; Seanski et al. 2005; Akbar et al., 2006; Ali et al., 2010; Sudika et al., 2015).The higher dominance gene action and lower narrow-sense heritability for 100-grain weight suggested that the hybrid selection based on 100-grain weight may be helpful to develop higher potential hybrids of maize to improve grain yield per plant (Kumar et al. 1999). Various researchers suggested higher dominance as selection criteria for the development of higher-yielding maize hybrids (Saleem et al., 2002; Holland et al., 2003; Kumar et al., 2005; Azizi et al., 2010).

When evaluating the results it should be remembered that these DH-lines were obtained using a very restricted genetic base (a single F1 hybrid), involving two inbred lines of tropical origin. The 5 DH lines tested only made it possible to experiment with an extremely low sample number. If the work were expanded to include DH lines with a broader genetic background and a higher number of cross combinations, there may be the possibility of more genetic variability and better combinations (Spitko et al., 2010). On the other hand, a low-yielding tester was used as a male parent in the cross combination with the female doubled haploid lines. If some higher-yielding male parents or these doubled haploid lines were crossed with each other, the results might be more promising. These lines can also be exploited for DH-hybrid development by inter-crossing them in diallel fashion to further exploit their genetic potential for yield and yield contributing traits.

Conclusions

The doubled haploid lines developed from a single donor source (F1 hybrid) possessed significant variability. The total variability present in these doubled haploid DH-lines was mostly genetic and hence, could be effectively utilized in maize breeding programs. These doubled haploid DH-lines can directly be utilized for varietal development.

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References

Aditya JP, Verma SS,Bhartiya A,Kar CS, 2010. Genetic analysis of important characters in aquality protein maize composite at two plant densities. Crop Improvement 37:13-20

Akbar M, Shabbir M, Amer H, Sarwar, M 2006. Evaluation of maize three way crosses through genetic variability, broad sense heritability, character association and path analysis. J Agri Res 46:39-45

Alam AK, Ahmed MM,Begum S,Sultan MK, 2008. Heterosis and combining ability for grain yield and its contributing characters in maize. Bangladesh J Agri Res 33:375-379

Ali AW, Hasan K, Samir A, 2010. Genetic variances, heritability, correlation and path coefficient analysis in yellow maize crosses (*Zea mays* L.). Agri Bio J N Amer 1:630-637

Ali Q, Ahsan M, Ali F,Aslam M,Saleem M, 2013. Heritability, heterosis and heterobeltiosis studies for morphological traits of maize (*Zea mays* L.) seedlings.Advancements Life Sci1:52-63

Ali Q, Ali A, Ahsan M,Ashraf MA, 2014. Line×Tester analysis for morpho-physiological traits of (*Zea mays* L.) seedlings. Advancements Life Sci 1:242-253

Aly RSH, Metwali, EMR,Mousa STM, 2011. Combining ability of maize (*Zea mays* L.) inbred lines for grain yield and some agronomic traits using topcross mating deseign. Global J Mol Sci 6:1-8

Amanullah SJ, Mansoor M,Khan MA, 2011. Heterosis studies in diallel crosses of maize. Sarhad J Agric 27:207-211

Amiruzzaman M, Islam MA,Pixel KV,Rohman MM, 2011. Heterosis and combining ability of CIMMYT's tropical × sub-tropical quality protein maize germplasm. Int J Sustainable Agri3:76–81

Appunu C, Satyanarayana E, 2007. Heterosis for grain yield and its components in maize (Zea mays L.). Plant Sci J 35:27-30

Ashrai M, McNelly T, 1990. Improvement of salt tolerance in maize by selection and breeding. Plant Breeding 104:101-107

Ayub M, Nadeem S, SahrarM, Mahmood N, 2002. Response of maize (*Zea mays* L.) fodder to different levels of nitrogen and phosphorus. Asian J Plant Sci 10:352-354

Azizi F, Rezaie AM, Saeidi G, 2010. Generation mean analysis to estimate genetic parameters for different traits in two crosses of corn inbred lines at three planting densities.J Agri Sci Tech8:153-169

Bajaj M, Verma SS, Kumar A, Kabdal MK, Aditya JP, Narayan A, 2007. Combining ability analysis and heterosis estimates in high quality protein maize inbred lines. Indian J Agri Res 41:49-53.

Buckler ES, Holland JB, Goodman MM, 2009. The genetic architecture of maize flowering time. Sci325:714-718.

Bhavana P, Singh RP, Gadag RN, 2011. Gene action and heterosis for yield and yield components in maize (*Zea mays* L.). Indian J Agri Sci 81:163-166.

Brieger FG, 1930. Selbst- und Kreuzungssterilitat. Berlin: Julius Springer

Brieger FG, 1944. Estudosexperimentaissobreorigiem do milho. An. Esc Sup Agric 2:225-278.

Brieger FG, 1949. Heterosis in population genetics and evolution. Palanza meeting 1948

Bruce AB, 1910. The Mendelian theory of heredity and the augmentation of vigor. Sci 32:672-628.

Collins GN, 1918. Intolerance of maize to self-fertilization. J WashintonAcadamy Sci 9:309-312.

CoorsJG, Pandey S, 1999.Genetics and exploitation of heterosis in crops. Crop Sci Society AmerMadison, WI.
Devi IS, Muhammad S, 2001. Character association and path coefficient analysis of grain yield and yield components in double crosses of corn. Crop Res 21:355-359.
Devi B, Barua NS, BaruaPK, Talukar P, 2007. Analysis of mid parent heterosis in a variety diallel in rainfed maize. Indian J Genet Plant Breed 67:67-70.
Dickert TE, Tracy WF, 2002. Heterosis for flowering time and agronomic traits among early open pollinated sweet corn cultivars. J Am Soc Hort Sci 127:793-797.
DuvickDN,1999. Inthe genetics and exploitation of heterosis in crops,Heterosis. Crop Sci Soc. AmerMadison Pp19-30.
Duvick DN, 2005. Genetic progress in yield of United States maize (*Zea mays* L.).Maydica 50:193
East EM,Hayes HK, 1912. Heterozygosis in evolution and in plant breeding. Bull US Dept Agric 243:7-58.
East EM, 1936. Heterosis. Genet 21:375-397.
Falconer DS, Mackay T F C 1996. Introduction to quantitative genetics. 4th (eds.), Longman, London
Falconer DS, 1989. Introduction to Quantitative Genetics. 3rd Edition, Longman, New York.
Flint-Garcia SA, BucklerES, Springer NM, 2009. Heterosis is prevalent for multiple traits in diverse maize germplasm.PloS one.4:33-74.
Flint-GarciaSA.,Thuillet, A.C.,Pressoir,J. Yu, G.,Romero,S.M.,Buckler,E. S. 2005.Maize association population: A high-resolution platform for quantitative trait locus dissection. Plant J.44:1054-1064.
Frascaroli, E., Cane, M. A. Landi, P., Pea, G., Gianfranceschi, L. Villa, M., Morgante,M., Pe, M. E. 2007. Classical genetic and quantitative trait loci analyses of heterosis in a maize hybrid between two elite inbred lines. Genet. 176:625-644.
Geeta K, 2001. Heterosis in maize (*Zea mays* L.). Agric Sci Digest 21:202-203
Guimaraes PD, Paterniani GZ, Luders RR,Souza AP,LabordaPR,Oliveira KM, 2007. Correlation between the heterosis of maize hybrids and genetic divergence among lines. PesquiAgropecu Bras J 42:811-816
Hallauer AR, CarenaMJ, Miranda FJB, 2010. Quantitative Genetics in Maize Breeding. Springer Science and Business Media, New York
Hefny MM, 2007. Estimation of quantitative genetic parameters for nitrogen use efficiency in maize under two nitrogen rates. Interl J Plant Breed Genet 1:54-66
Hefny M, 2010. Genetic control of flowering traits, yield and its components in maize (*Zea mays* L.) at different sowing dates.Asian J Crop Sci2:236-249.
Holland JB, WE Nyquist, MartínezCT, 2003. Estimating and interpreting heritability for plant breeding: an update.Plant breed reviews22:9-112.
Hull FH, 1945. Recurrent selection and specific combining ability in corn. J Amer Soc Agron 37:134-145.
Ikramullah IH, Khalil M, Shah MKN, 2011. Heterotic effects for yield and protein content in white quality protein maize. Sarhad J Agric 27:403-409.
Ilke E, Tonk FA, Çaylak O, TosunM, Özmen I, 2009. Assessment of genotype × environment interactions for grain yield in maize hybrids using AMMI and GGE biplot analyses. Turk J Field Crops 14:123-135.
Iqbal AM, Nehvi FA, Wani SA, QadirR, Dar ZA, 2007. Combining ability analysis for yield and yield related traits in Maize (*Zea mays* L.).International J Plant Breed Genet 1:101-105.
Jain R, Bharadwaj DN, 2014. Heterosis and inbreeding depression for grain yield and yield contributing characters in quality protein maize. Agri Community2:8-16.
Jaya J, Sundram T, 2007. Combining ability studies for grain yield and other yield components in maize. Crop Res 33:179-186.
Ji HC, Woong J, Yamakawa T, 2006. Diallel analysis of plant and ear heights in tropical maize (*Zea mays* L.). J Fac Agr 51:233-238.
Kanagarasu S, Nallathambi G, Ganesan KN, 2010. Combining ability analysis for yield and its component traits in maize (*Zea mays* L.).Electronic J Plant Breed 1:915-920
Kara SM, 2001. Evaluation of yield and yield components in inbred maize lines. Heterosis and line×tester analysis of combining ability. Turk J Agri 25:383-391.
Katana G, Singh HB, Sharma JK, Guleria SK, 2005. Heterosis and combining ability studies for yield and its related traits in maize (*Zea mays* L.). Crop Res 30:221-226.
Keeble F, Pellew C, 1910. The mode of inheritance of stature and of time of flowering in peas (Pisumsativum). J Genet 1:47-56.
Khan NH, Ahsan M, SaleemM, Ali A, 2014.

Genetic association among various morpho-physiological traits of maize under drought condition.Life Science Journal11:112-122.
Khan HZ, Malik MA, Saleem MF, 2008. Effect of rate and source of organic material on the production potential of spring maize (*Zea mays* L.). Pak J Agric Sci 45:40-43.
Khodarahmpour Z, Hamidi J, 2012. Study of yield and yield components of corn (*Zea mays* L.) inbred lines to drought stress. African J Biotech 11:3099-3105.
Knapp SJ, Stroup WW, Ross WM, 1985. Exact confidence intervals for heritability on a progeny mean basis.Crop Sci25:192-194.
Konak C, Aydın U, Basal H, Serter E, 2015. Combining ability and heterotic effects in some characteristics of second crop maize. Turk J Field Crops 6:64-70.
Kumar MVN, Kumar SS, Ganesh M, 1999. Combining ability studies for oil improvement in maize. Crop Res Hisar 18:93-9.
Kumar R, Singh M, NarwalMS, Sharma S, 2005. Gene effects for grain yield and its attributes in maize (*Zea mays* L.).N J Plant Imp7:105-107.
Kutlu İ,Sırel Z, 2019. Using line × tester method and heterotic grouping to select high yielding genotypes of bread wheat (*Triticum aestivum* L.). Turk J Field Crops 24:185-194.
Makumbi D, Pixley K, Banziger M, Betrán KJ, 2005. Yield potential of synthetic maize varieties under stress and non-stress conditions. Proc. Int. African crop sci 7:1193-1199.
Malik HN, Malik SI, ChughtaiSR, Javed HI, 2004. Estimates of heterosis among temperate, sub-tropical and tropical maize germplasm. Asian J Plant Sci 3:6-10.
MalvarRA, OrdasA, Cartea ME, 1996. Estimates of genetic variances in two Spanish populations of maize.Crop sci36:291-295.
Manivannan NA, 1998. Character association and components analysis in corn. Madras J Agric 85:293-294.
Meghji MR, DudleyJW, Sprague GF, 1984. Inbreeding depression, inbred and hybrid grain yields, and other traits of maize genotypes representing three eras.Crop Sci24:545-549.
MelchingerAE, Gumber RK,1998. InConcepts and breeding of heterosis in crop plants,Overview of heterosis and heterotic groups in agronomic crops. Crop Sci Soc AmerMadison, WI.29-44.
Meseka SK, Menkir A, Ibrahim AES, Ajala SO, 2006. Genetic analysis of performance of maize inbred lines selected for tolerance to drought under low nitrogen. Maydica 51:487-495.
Mickelson SM, Stuber CS, Kaeppler SM, 2002. Quantitative trait loci controlling leaf and tassel traits in a B73× Mo17 population of maize.Crop Sci.42:1902-1909.
Muraya MM, Ndirangu CM, Omolo EO, 2006. Heterosis and combining ability in diallel crosses involving maize (*Zea mays* L.) S1 lines. Animal Production Science46:387-394.
Nathan M,Stupar RM, 2007. Allelic variation and heterosis in maize: How do two halves make more than a whole? Genome Res17:264-275.
Noor M, Rahman H, Iqbal M, 2017. Heritability estimates for maturity and plant characteristics in popcorn. 2017. Sarhad J Agric 33:276-281.
Ojo GOS, Adedzwa DK, Bello LL, 2007. Combining ability estimates and heterosis for grain yield and yield components in maize (*Zea mays* L.). J. Sust Dev Agric Envir 3:49-57.
Peiffer JA, Spor A, Koren O, 2013. Diversity and heritability of the maize rhizosphere microbiome under field conditions.Proc Int Academy Sci. 110:6548-6553.
Prasanna BM, 2014. Proc 12th Int AMC Conf, 30 October, Bangkok
Rafique M, Amer H, Tariq M, Alvi AW, 2004. Heritability and interrelationships among grain yield and yield components in maize (*Zea mays* L.). Int J Agri Bio 6:1113-1114.
Rajitha A, 2013. Combining ability and gene action in maize (*Zea mays* L.). M.Sc. Diss., Acharya N G Ranga AgricUniv Hyderabad, India
Rasmusson J, 1933. A contribution to the theory of quantitative character inheritance. Hereditas 18:245-261.
Revilla P, Rodriguez VM, Malvar RA, Butron A, Ordas A, 2006. Comparison among sweet corn heterotic patterns. Amer Soc Hort Sci J 131:388-392.
Saleem M, Shahzad K, Javid M, AhmedA, 2002. Genetic analysis for various quantitative traits in maize (*Zea mays* L.) inbred lines.Int J Agri Bio4:379-382.
Sanghi AK, AgarwalKN, Qadri MI, 1982. Gene effects and heterosis for grain yield and ear traits in maize.Indian J Genet Plant Breed42:360-363.
Seanski M, Zivanovic T, Todorovic G, 2005. Components of genetic variability and heritability of the number of rows per ear in silage maize. Biotech. Animal Husbandry 21:109-121.
Sekip, E, Mehmet P, Osman S, Mehmet T. 2011. Evaluation of developed standard sweet corn (*Zea mays sacharata* L.) hybrids for fresh yield, yield components and quality parameters. Turk

J Field Crops16:153-156.
Shah STH, Zamir MSI, Waseem MM, TahirA, Khalid WB, 2009.Growth and yield response of maize (Zea maysL.) to organic and inorganic sources of nitrogen. Pak J Life Social Sci 7:108-111.
Shull GH, 1911. Hybridization methods in corn breeding. Amer Breeders Mag 1:98-107.
Singh DN, Singh IS, 1998. Line×Tester analysis in maize (Zea mays L.). J Res 10:177-182.
Solomon KF, Zeppa A, Mulugeta SD, 2012. Combining ability, genetic diversity and heterosis in relation to F1 performance of tropically adapted shrunken (sh2) sweet corn lines.Plant breed131:430-436.
Spitkó T, Laszlo S, Pintér J, MartonLC, Barnabás B, 2010. General and specific combining ability of in vitro doubled haploid maize lines in the field. ActaAgronHungarica 58:167-177.
Stansfield WD, 1991. Theory and Problems of Genetics. Mc. Graw Hills, Book Company.
Steel RGD, Torrie JH, Dickey DA, 1997. Principles and procedures of statistics: A biometrical approach. 3 ed New York: McGraw-Hill Publ Company.
Subramaniyan A, Subbraman N, 2006. Combining ability analysis for yield and its contributing traits in maize. Indian J Agric Res 40:131-134.
Sudika I, Wayan NB, Andy S, 2015. Estimation of genetics variance components from composite and hybrid maize (Zea mays L.) hybridization. Int J Plant Res 5:107-112.
Sujiprihati S, Saleh GB, Ali ES, 2003. Heritability, performance and correlation studies on single cross hybrids of tropical maize.Asian J Plant Sci2:51-57.
Sumalini K, 2012. Combining ability and heterosis for yield and quantitative traits in maize. Madras Agri J 99:188-191.
Tollenaar M, Ahmadzadeh A, Lee EA, 2004. Physiological basis of heterosis for grain yield in maize.Crop Sci,44:2086-2094.
Troyer AF, 2006. Adaptedness and heterosis in corn and mule hybrids.Crop Sci, 46:528-543
Vijaya A, AnandakumarCR, Gnanamalar RP, 2009. Combining ability analysis for yield and its components in popcorn. Electronic J Plant Breed 1:28-32.
Wannows AA, Azzam HK, Al-Ahmad SA, 2010. Genetic Variances, Heritability, Correlation and Path Coefficient Analysis in Yellow Maize Crosses (Zea mays L.). Agric Bio J North Amer 1:630-637.
Woodhouse MR, Freeling M, Lisch D, 2006. Initiation, establishment, and maintenance of heritable MuDR transposon silencing in maize are mediated by distinct factors.Plos Bio4:339
Yadav TP, Singh RD, Bhat JS, 2002. Genetic analysis in varietal crosses of maize (Zea mays L.). New Botanist 29:131-140.
Yang A, Zhang S,RongML, Pan TG, 2005. Combining ability and heterosis of 14 CIMMYT and 13 domestic maize populations in an NC II mating design.Chinese J Tropical Crops32:1329-1337.
Zsubori Z, Gyenes-Hegyi, Illés Z, Pók O, Rácz O,Szőke FC, 2019. Inheritance of plant and ear height in maize (Zea mays L.). Hungarian Academy Sci 1:1-6.