International Journal of Plant & Soil Science

34(22): 510-518, 2022; Article no.IJPSS.86107
ISSN: 2320-7035

Assessing Combining Ability of Doubled Haploid Maize (*Zea mays* L.) Breeding Lines for Grain Yield and Yield Components under Heat Stress Condition

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i2231403

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/86107

Original Research Article

Received 18 March 2022
Accepted 26 April 2022
Published 10 August 2022

ABSTRACT

Maize (*Zea mays* L.), a leading cereal worldwide and staple food of many countries, is a multipurpose crop used for human food, animal feed and industry purposes. Maize has wider genetic adaptability to grow under different agro-ecological environments. 29 and 48 DH lines derived from MPS 1 and MPS 2, respectively, were crossed with more than one testers belonging to opposite heterotic in L x T fashion. The resultant double haploid testcrosses, and their parents were evaluated along with checks during *kharif* (in South Asia: the autumn crop sown at the beginning of the summer rains) 2019 at three locations. Among female lines of MPS1, DH line ZL19337 was identified as good general combiner and registered significant negative GCA effect

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for days to 50 per cent anthesis and days to 50 per cent silking. While, DH lines ZL19641 and ZL19357 recorded significantly positive GCA for plant height and grain yield, respectively. Among female lines of MPS 2, DH line ZL19492 was identified as good general combiner and recorded significant negative GCA effects for days to 50 per cent anthesis, and days to 50 per cent silking. Similarly, DH lines, ZL19534 and ZL19572 were identified as good general combiners for grain yield and ear position, respectively. Among testers of MPS1, ZL1840 was identified as the good general combiner for days to 50 per cent anthesis, days to 50 per cent silking and plant height and CAL14113 for ear height and grain yield. Similarly, VL1010996 was identified as the good general combiner for days to 50 per cent anthesis, days to 50 per cent silking, plant height, ear height, ear position and grain yield in MPS 2. Hybrid ZH2063 exhibited desired SCA effects for days to 50 per cent anthesis and days to 50 silking and ZH2010 was identified as a good specific combiner for days to 50 per cent anthesis and grain yield in MPS 1. Hybrid ZH20158 recorded desirable SCA effects for the trait days to 50 silking, While, ZH20251 and ZH20183 were identified as good specific combiners for plant height and grain yield in MPS 2.

Keywords: General combining ability; specific combining ability; multiparent synthetic population (MPS); doubled haploids maize.

1. INTRODUCTION

Maize (*Zea mays* L.), a leading cereal worldwide and staple food of many countries, is a multipurpose crop used for human food, animal feed and industry purposes (Deryng et al. 2014). Crop plants in general are sensitive to high temperature at reproductive phase. High temperature beyond optimum level causes irreversible damages to plant growth, resulting in the drop in crop productivity. Rapid changes in harsh climate resulted in a huge decrease in cereal productivity, and so the world food production (Deryng et al. 2014). High temperature (2°C) beyond the threshold level has more drastic effects on crop yield compared to low (20%) precipitation (Lobell and Burke, 2010; Shahid et al. 2017). Under heat stress environment, leaf temperature, water relations and stomatal conductance severely affect the plant growth. These three factors are collectively known as the “magic triangle” for plants (Valladares and Pearcy, 1997). The average yield of maize is low because of various biotic and abiotic stresses. Chen et al. (2010) reported that when maize plant reaches up to 8^{th} leaf stage, it becomes susceptible to high temperature stress. The high temperature associated with drought causes a decline in yield at reproductive and grain filling stages of the maize crop. Spring maize crop, faces heat stress at anthesis and grain filling (soft-dough/ milky stage) period which reduces pollen viability, silk receptivity and grain weight (Reynolds-Henne et al. 2010). High temperature coupled with limited water urges breeder to develop hybrids, which can withstand heat stress without a remarkable decline in yield (Tester and Bacic, 2005). The primary goal in developing heat-tolerant hybrids is; to cope with heat stress at reproductive and grain filling stages and harvest a successful crop. Nowadays the development of heat resilient cultivars is a challenging task. The narrow base genetic diversity of crop acts as major hindrance in achieving this goal. Breeders got few successes in the development of heat-tolerant genotypes, because the genetic basis of heat tolerance in various agronomic and physiological traits is largely unknown (Driedonks et al. 2016). Heat tolerance is a complex and multigene inherited trait with slow progress because of G × E (Chen et al. 2012).

Though both stresses (biotic and abiotic) have adverse effects on maize yield, a low correspondence in maize cultivars is identified individually for tolerance to heat stress. Heat stress is likely to become an increasing constraint to maize production. Similarly, a recent study is conduct indicated that increasing temperatures would result in a greater reduction in maize yields than increased intra-seasonal variability in precipitation. These studies highlight the need to incorporate tolerance to heat into maize hybrids to onset predicted yield losses due to heat stress. Therefore, an attempted was made to assess the general combining ability and specific combining ability among the selected superior parental lines and double haploid testcrosses for grain yield and yield compounds in maize (*Zea Mays* L.) under heat stress.

2. MATERIALS AND METHODS

The material for the present study consisted of 29 and 48 DH (Double haploid) lines respectively, from Multiparent synthetic population (MPS1) and Multiparent synthetic population (MPS2) which were crossed to more than one testers belonging to opposite heterotic group during late *kharif* 2019. These selected DH lines were crossed with proven testers from opposite heterotic group in Design-II and new hybrid combinations developed during *kharif* 2019. New hybrid combinations generated from DH lines of MPS 1 and 2 crossed with five and four different testers from opposite heterotic groups. The resultant double haploid testcrosses were evaluated in alpha lattice design with two replications under heat stress at three locations *viz.,* IIMR, Begusarai, BISA, Ludhiana and Main Agricultural Research Station, Raichur, during *spring* 2020. These DH testcrosses were planted with a spacing of 60 cm between rows and 20 cm between plants. After thorough land preparation, seeds were hand dibbled at the rate of one seed per hill. The crop was applied with a recommended dose of fertilizers (150 kg N, 75 kg P_2O_5 and 40 kg K_2O beside organic manures). Standard agronomic practices were followed to raise the healthy crop. The data on various quantitative traits *viz*., days to 50 per cent anthesis (d), days to 50 per cent silking (d), anthesis-silking interval (d), plant height (cm), ear height (cm), ears per plant, ear position, and grain yield (t ha^{-1}) were recorded on five randomly selected plants. The mean data was analysed using META-R and AGD.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance for Combining Ability of DH Lines Derived from MPS 1 Crossed with Different Testers under Heat Stress

The variance due to females was highly significant for days to 50 per cent anthesis, days to 50 per cent silk, anthesis to the silking interval, plant height, ear height, ear position and grain yield (Table 1). The variance due to testers was highly significant for 50 per cent anthesis, days to 50 per cent silking, plant height, ear height, ear position and grain yield indicating that the DH lines and testers used for the study exhibited a lot of variabilities. The variances due to line × tester interactions were highly significant for plant height, ear height and grain yield indicating the scope of exploitation of heterosis. The variance due to site × genotype was highly significant for grain yield indicating differential expression of yield at different locations. The variance due to site × line was highly significant for plant height and grain yield. The variance due to site × tester was highly significant for grain yield. The variance due to site × line × tester was highly significant for anthesis to silking interval, ear height and grain yield. These results are in accordance with the findings of Archana [1] and Divya [2] in their study.

3.2 Analysis of Variance for Combining Ability of DH lines Derived from MPS 2 Crossed with Different Testers under Heat Stress

The variances due to lines were highly significant for days to 50 per cent anthesis, days to 50 per cent silking, ear position, ears per plant, ear height, plant height and grain yield indicating the variability among the DH lines. The variance due to tester was highly significant for 50 per cent anthesis, days to 50 per-cent silk, ear position, ear height, plant height and grain yield indicating the presence of variability among testers. The variance due to line × tester interaction was highly significant for ear height, plant height and grain yield indicating scope of exploitation of heterosis. The variance due to site × genotype was highly significant for ears per plant, plant height, ear height and grain yield, indicating differential expression of yield at different locations. The variance due to site × line was highly significant for days to 50 per cent anthesis, ears per plant, ear height, plant height and grain yield. The variance due to site × tester was highly significant for ear height and grain yield. The variance due to site × line × tester was highly significant for grain yield (Table 2). Archana [1] and Divya [2] also reported similar results under heat stress.

3.3 General Combining Ability (GCA) Effects of Parents of DH Lines under Heat Stress

The top three desirables doubled haploid lines and testers were selected from the trial based on their GCA effects for selected traits and presented in Table 3 along with their mean performance status under heat stress condition. The GCA effects from MPS 1 suggested that doubled haploid line ZL19337 was a good general combiner and registered significant negative GCA effect for days to 50 per cent anthesis and days to 50 per cent silking

Table 1. Analysis of variance for combining ability for various traits under heat stress conditions across locations in DH lines derived from MPS 1 (HGA) crossed with different testers

Source	Degrees of freedom	Days to 50% anthesis (d)	Days to 50% silking (d)	Anthesis to silking interval (d)	Plant height (cm)	Ear height (cm)	Ears per plant	Ear position	Grain yield (t ha^{-1})
Site	2	15956**	15156.7**	171.93**	4248.42**	11303.66**	0.12*	0.68**	66.73**
Rep (Site)	3	117.63**	135**	0.81	1218.63**	906.72**	0.08	0.02**	29.24**
Genotypes	132	14.18**	15.90**	0.62	413.41**	146.57**	0.04	0**	3.01**
Line	28	24.16**	29.26**	0.81*	1048.49**	331.99**	0.05	0.01**	4.19**
Tester	5	110.9**	122.73**	0.99	2207.82**	449.65**	0.05	0.01**	7.98**
Line:tester	99	6.44	6.61	0.55	142.92**	78.93*	0.05	0	2.29**
Site:Genotypes	264	4.69	5.25	0.55	99.05	59.90	0.04	0	1.92**
Site:Line	56	5.05	5.95	0.52	141.25**	64.51	0.04*	0	2.27**
Site:Tester	10	2.55	3.42	1.16	124.63	131.49	0.05	0**	4.31**
Site:Line:Tester	198	4.69	5.14	0.53**	85.82	54.98**	0.04	0	1.69**
Residuals		5.11	5.14	0.49	81.11	55.69	0.03	0	1

**, ** significant at 5 % and 1 % level of probability, respectively*

Table 2. Analysis of variance for combining ability for various traits under heat stress condition in DH lines derived from MPS 2 (HGB) crossed with different testers

Source	Degrees of freedom	Days to 50% anthesis (d)	Days to 50% silking (d)	Anthesis to silking interval (d)	Plant height (cm)	Ear height (cm)	Ears per plant	Ear position	Grain yield (t ha^{-1})
Site	2	9037.84**	8428.09**	134**	8520.19**	14263.96**	0.24**	0.45**	9.99**
Rep (Site)	3	55.97**	64.06**	0.67	1198.26**	1057.13**	0.29**	0.01**	30.56**
Genotypes	160	13.21**	14.43**	0.38	580.90**	406.47**	0.03*	0.01**	3.22**
Line	47	24.07**	26.82**	0.45	803.58**	594.07**	0.04**	0.01**	4.74**
Tester	4	98.46**	106.26**	0.23	9467.55**	6330.97**	0.05	0.08**	11.62**
Line:tester	109	5.43	5.73	0.35	159.17**	108.53**	0.02	0**	2.19**
Site:Genotypes	320	5.71	5.81	0.53	110.95*	92.39**	0.03**	0**	2.17**
Site:Line	94	6.53*	6.18	0.51	147.20**	94.40**	0.03**	0	2.56**
Site:Tester	8	6.07	7.56	0.60	164.32	260.05**	0.03	0**	4.84**
Site:Line:Tester	218	5.34	5.59	0.53	93.36	85.38*	0.03*	0**	1.91**
Residuals		4.76	5.06	0.47	88.28	65	0.02	0	1.05**

*, ** significant at 5 % and 1 % level of probability, respectively

Table 3. Top three DH lines derived from MPS 1 (HGA), MPS 2 (HGB) and testers that exhibited desirable *gca* effects for selected traits under heat stress

Characters	MPS 1 (HGA)				MPS 2 (HGB)			
	Females		Males		Females		Males	
Days to 50% anthesis	ZL19300	-1.02*	ZL1840	-1.62	ZL19492	-2.08**	VL1010996	-1.18
	ZL19729	-1.22**	ZL18129	-0.26	ZL19507	-1.27*	CAL1733	-0.02
	ZL19337	-0.77	ZL19290	0.05	ZL19602	-0.97*	ZL155186	0.03
Days to 50% silking	ZL19300	-1.05*	ZL1840	-1.75	ZL19492	-2.44**	VL1010996	-1.19
	ZL19337	-1.07*	ZL18129	-0.34	ZL19483	-1.55**	CAL1733	-0.08
	ZL19729	-1.52**	ZL19290	0.12	ZL19507	-1.27*	ZL155186	0.11
Plant height	ZL19641	14.52**	ZL18129	4.79	ZL19524	7.36**	CAL1733	10.61
	ZL19897	9.42**	ZL1840	4.58	ZL19820	7.07**	ZL1861	1.95
	ZL19731	7.93**	ZL19290	0.24	ZL19753	7.00*	ZL155542	0.76
Ear height	ZL19309	-7.32**	ZL11959	-1.49	ZL19483	-9.48**	ZL155186	-10.07
	ZL19337	-4.61**	CAL14113	-1.20	ZL19630	-8.51**	VL1010996	-3.32
	ZL19299	-3.19*	ZL19290	-0.29	ZL19479	-7.60**	ZL1861	2.95
Grain yield	ZL19357	0.17	CAL14113	0.03	ZL19534	0.25	CAL1733	0.16
	ZL19304	0.15	ZL18129	0.03	ZL19572	0.25	ZL155542	0.05
	-	-	-	-	ZL19611	0.23	ZL1861	-0.02
Ear position	-	-	-	-	ZL19479	-0.03**	ZL155186	-0.03
	-	-	-	-	ZL19534	-0.02**	VL1010996	-0.01
	-	-	-	-	ZL19572	-0.02*	ZL1861	0.01

**, ** significant at 5 % and 1 % level of probability, respectively.*

Table 4. Top three hybrids that exhibited desirable *sca* effects for selected traits in MPS 1 (HGA) and MPS 2 (HGB)

Characters	MPS 1 (HGA)				MPS 2 (HGB)			
	Parents	**Hybrids**	***sca* effect**	**Mean performance**	**Parents**	**Hybrids**	***sca* effect**	**Mean performance**
Days to 50% silking (d)	ZL19656 x ZL19290	ZH2063	-0.44	61.48	ZL19456 x CAL1733	ZH20158	-0.01	60.61
	ZL19666 x ZL1840	ZH2070	-0.39	61.95	ZL19507 x CAL1733	ZH20161	-0.01	61.25
	ZL19362 x ZL1840	ZH2025	-0.39	62.55	ZL19611 x ZL155186	ZH20199	-0.01	61.77
Plant height (cm)	ZL19428 x ZL1840	ZH2050	6.25	154.99	ZL19791x ZL155542	ZH20251	3.66	162.60
	ZL19641 x ZL18129	ZH2073	3.59	151.02	ZL19753 x ZL1861	ZH20216	3.32	142.91
	ZL19731 x ZL11959	ZH2089	3.40	157.96	ZL19939 x VL1010996	ZH20275	3.19	166.70
Ear height (cm)	ZL19309 x CAL14113	ZH20105	-2.56	75.22	ZL19939 x CAL1733	ZH20276	-1.96	77.09
	ZL19361 x CAL14135	ZH2021	-2.43	67.64	ZL19991 x CAL1733	ZH20283	-1.40	91.83
	ZL19321 x ZL18129	ZH20112	-2.32	77.55	ZL19630 x CAL1733	ZH20208	-1.16	83.88
Grain yield (t ha^{-1})	ZL19304 x CAL14113	ZH2010	0.69	4.70	ZL19572 x ZL155542	ZH20183	0.35	4.30
	ZL19424 x ZL1840	ZH2045	0.48	4.85	ZL19596 x CAL1733	ZH20188	0.32	4.68
	ZL19361 x ZL18129	ZH2019	0.36	4.76	ZL19619 x CAL1733	ZH20204	0.30	4.41
Days to 50% anthesis (d)	ZL19656 x ZL19290	ZH2063	-0.44	59.01	-	-	-	-
	ZL19304 x CAL14113	ZH2010	-0.43	59.60	-	-	-	-
	ZL19357 x ZL18129	ZH20134	-0.42	58.91	-	-	-	-

While, doubled haploid lines ZL19641 and ZL19357 recorded significantly positive GCA for plant height and grain yield, respectively, among female lines.

In a similar way, ZL1840 was identified as the good general combiner for the traits days to 50 per cent anthesis, days to 50 per cent silking and plant height and CAL14113 for the traits *viz.,* ear height and grain yield among testers. Previously, Dinesh et al. [3], Geetha et al. [4], Gazala et al. [5], and Krishnaji et al. [6] also identified good general combiners for various traits including grain yield, under heat stress conditions.

The GCA effects from MPS 2 crossed with different testers suggested that line ZL19492 was a good general combiner and showed significant negative GCA effects for days to 50 per cent anthesis, and days to 50 per cent silking (Table 3). Double haploid lines *viz.,* ZL19534 and ZL19572 were identified as good general combiners for grain yield and ear position among female lines. Among testers, VL1010996 was identified as the good general combiner for the traits *viz.,* days to 50 per cent anthesis, days to 50 per cent silking, plant height, ear height, ear position and grain yield. Following the present findings, previously, Gazala et al. [5], Krishnaji et al. [6] and Geetha et al. [4] identified good general combiners for various traits including grain yield, under heat stress conditions.

3.4 Specific Combining Ability (*sca*) Effects of Hybrids in under Heat Stress

Top three desirables hybrids were selected from the trial based on their *sca* effects for selected traits and presented in Table 4 along with their mean performance status under heat stress condition. The cross combinations, ZL19656 x ZL19290 = ZH2063 exhibited desired *sca* effects for traits *viz.,* days to 50 per cent anthesis and days to 50 silking. While, the hybrid combination ZL19304 x CAL14113 = ZH2010 was identified as a good specific combiner for days to 50 per cent anthesis and grain yield. Previously, Gazala et al. [5], Krishnaji et al. [6] and Geetha et al. (2019) identified good specific combiners for grain yield and its contributing traits under heat stress conditions.

The SCA effects for MPS2 are presented in Table 4 along with their mean performance status under heat stress condition. The cross combination, ZL19456 x CAL1733 = ZH20158 exhibited desirable SCA effects for the trait days to 50 silking, while ZL19791 x ZL155542 = ZH20251 was a good specific combiner for plant height and ZL19572 x ZL155542 = ZH20183 was a good specific combiner for grain yield. Previously, Gazala et al. [5], Krishnaji et al. (2018) and Geetha et al. [4] identified good specific combiners for grain yield and its contributing traits under heat stress conditions. The DH lines/testers of the above testcrosses and new combinations could be considered for producing new hybrids with the proven seed parents already available with the programme.

4. CONCLUSION

The combining ability studies revealed that the traits *viz.,* 50 per cent silking, ear position and grain yield were predominantly controlled by non-additive gene action in testcrosses produced from DH lines of MPS 1. However, the magnitude of GCA variance was larger than SCA variance for days to 50 per cent anthesis, ear height and plant height indicating the predominance of additive gene action than non-additive gene action in the inheritance of these traits. The magnitude of GCA variance was equal to SCA variance for anthesis to silking interval indicating the predominance of both additive gene action and non-additive gene action in the inheritance of anthesis to silking interval.

GCA and SCA variance for various traits in testcrosses produced from DH lines of MPS 2 revealed higher magnitude of GCA variance than SCA variance for the characters days to 50 per cent anthesis, days to 50 per cent silk, anthesis to silking interval and ear position indicating the predominance of additive gene action in controlling these traits. However, the magnitude of GCA variance was lesser than SCA variance for days to silking, ear height and plant height indicating the predominance of non-additive gene action than additive gene action in the inheritance of these traits.

ACKNOWLEDGEMENT

Authors are very much thankful to USAID for the financial support through Heat stress tolerance maize for south Asia through public private partnership (HTMA-II) project.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/86107