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Genetic analysis of maize inbred lines (*Zea mays* L.) under sub-tropical conditions of Indian Shivalik hills

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Abstract
Aim: The present study was carried out to genetically analyses maize inbred lines (*Zea mays* L.) for their potential use in hybridization programme.
Methodology: Seven inbred lines *viz.,* UDMI-134, UDMI-135, UDMI-136, UDMI-143, UDMI-205, UDMI-206 and UDMI-215 were crossed with three testers *viz.,* HKI-1105, V-341 and V-351 during *kharif* 2016 in line x tester mating design. Resultant 21 cross combinations,10 parents and one hybrid check *viz.* PHM-12 were evaluated in Randomized Complete Block Design with three replications during *Kharif* 2017. Mean squares due to genotypes, parents, crosses and parents v/s crosses were significant for all the traits, except days to 50 per cent silking due to genotypes and test weight due to parents and days to 50 per cent silking due to parents vs crosses.
Results: The estimates of specific combining ability (SCA) variance were of higher magnitude than general combining ability (GCA) variance for all the traits. Ratio of $\sigma^2_{sca} / \sigma^2_{gca}$ was greater than one for all the traits except grain yield per plant indicating the preponderance of non-additive gene effects. UDMI-206 has been found good general combiner for grain yield, test weight, days to 50 per cent pollen shedding and days to 75 per cent brown husk. Among the testers V-351 has been found good general combiner for all the traits except 50 per cent silking and plant height. The significant positive SCA effects for grain yield per plant was observed in three hybrids *viz.* UDMI-205 X HKI-1105, UDMI-205 X V-341 and UDMI-134 X V-351. The hybrid UDMI-135 x V-341 manifested positive significant standard heterosis (23.30 percent) for grain yield per plant over the hybrid checks (PHM-12).
Interpretation: These superior cross combinations identified can be tested as single cross hybrids in multi location evaluation trials under sub-tropical conditions of northern Indian shivalik hills.

Keywords: Genetic analysis, Line x Tester, *Zea mays*, Combining ability

Introduction
Maize (*Zea mays* L.) 2n=20, belonging to tribe Maydeae of grass family, Poaceae is the third most important cereal crop after rice and wheat in the world. It is referred to as “queen of the cereals” due to its high productivity potential compared to other *Graminae* family members. Maize is a monoecious plant and the reproductive organs are partitioned into separate pistillate (ear-female organ) and staminate (tassel male organ) inflorescences. Maize is generally protandrous *viz.,* male spikelets mature earlier than the female thereby, leading to cross pollination. In India during kharif 2020 maize was cultivated over an area of 9.7 million hactares with production of 28.64 million metric tonnes and productivity 2.9 tonnes per hactare (Anonymous, 2020) [3]. In Jammu & Kashmir, it is cultivated on an area of 262.35 thousand hactares with production and productivity of 5744 thousand quintals and 21.89 quintals per hectare. (Anonymous, 2019) [2]. Maize hybrid technology had contributed a lot in enhancing maize production across the world. The higher yield of maize hybrids than composites accompanied by genetic enhancement of inbred parental lines involved in hybrid production is the main reason of its preference for commercial production. Single cross hybrids had substantially increased maize production and productivity not only at international but also at national level as well. The production of promising hybrids for commercial cultivation is only accomplished by a perfect parental combination, which can be judged by their combining abilities. Therefore, combining ability analysis is an effective tool for identifying superior parents for attempting hybrids.
Maize possesses enormous genetic and biological diversity which justifies the attention it continues to enjoy from geneticists and plant breeders. In any breeding program, the choice of the appropriate parents is the secret of the success. One of the most important criteria in breeding programs for identifying hybrids with high yield is knowledge regarding parent’s

genetic structure and information regarding their combining ability (Ceyhan, 2003) [6]. Maize breeders have used several biometrical techniques to study the genetic architecture of quantitative traits including grain yield. Amongst a large array of biometrical procedures for relative estimation of genetic components, line x tester is an effective procedure as it allows the inclusion of a large number of lines and provides reliable estimates of combining ability and gene action governing a complex trait.

Materials and Methods

Seven inbred lines and three established testers procured from AICRP maize centre Udhampur centre (Table 1) constitute the base material for the present study. These parental inbreds were selected from experimental material obtained from the winter nursery, Hyderabad and UPHSS, Almora, keeping in view the features manifested for requirement of single cross hybrids. These seven inbred lines as females were crossed with three inbred testers as males to generate twenty one single cross combinations. All the parental lines involved in mating design were also selfed to generate selfed seeds for next season evaluation along with the single crosses.

All twenty one single cross combinations along with ten parents *viz*., seven inbreds, three testers and one hybrid check *viz*., PHM-12 were planted in a Randomized Complete Block Design with three replications during the *Kharif* 2017. The hybrids and inbreds were randomized as separate groups within each replication to avoid competition between the parental lines and relatively more vigorous hybrids. All the recommended agronomical practices were followed for successful raising of the crop.

The weather condition during the cropping season (i.e. June to Oct.) at Chatha was favorable for normal growth and development. The total rainfall during the crop season was 914.4 mm (June –Oct. 2016) and 736.7 mm (June –Oct. 2017). Observations were recorded on various quantitative traits *viz*., Days to 50% Pollen Shed, Days to 50% Silking, Days to 75% Brown Husk, Plant Height, Test Weight and Grain yield per plant (no.). The combining ability analysis was carried out by the following method given by Kempthorne (1957) [12].

Results and Discussion

Analysis of variance revealed that mean squares due to genotypes, parents, crosses and parents v/s crosses were significant for all the traits except for days to 50 percent silking and test weight due to parents; days to 50 percent silking due to parents vs crosses (Table 2).The mean squares due to crosses were highly significant indicating that the crosses were different from each other for these traits and hence selection is possible to identify the most desirable cross combinations. The significance of parents vs hybrids mean squares indicated superiority (heterosis) of hybrids over parents for different quantitative characters. Data recorded in twenty one cross combinations was analysed and the total variance was partitioned into components *viz.*, variance due to lines, testers and line x testers (Table 3). It was further analysed to determine the lines and testers (GCA) and line x testers (SCA) variance components for all the traits. The mean squares due to testers and line x testers were significant for all the traits except days to 50% pollen shedding, days to 50% silking, days to 75% brown husk and test weight due to testers. However mean squares due to lines showed non-significance for all the traits except grain yield per plant. The significant mean squares for lines and testers indicated significant contribution of parents towards general combining ability variance components for these traits. The significant mean squares for line x testers indicated significant contribution of hybrids for specific combining ability variance components. Similar trends for variance and its components were also reported by Lal and Kumar (2012) [15], Anusheela *et al.* (2013) [4], Abrha *et al*. (2013) [1], Singh *et al.* (2013) [24], Motamedi *et al.* (2014) [17], Rajesh *et al.* (2014) [21], Ruswandi *et al*. (2015) [23], Khan *et al.* (2016) [13] and Bharti *et al.* (2017) [5] in their respective studies.

Variance due to lines was of higher magnitude than that of testers for days to 50 per cent silking and days to 75 per cent brown husk, test weight and grain yield per plant (Table 4). This indicated that the contribution of lines for these traits, towards σ^2_{gca} was greater. Variance due to testers was of higher magnitude than that of lines for all the traits except for these traits indicated the greater contribution of testers for these traits towards σ^2_{gca}. The estimates of SCA variance were of higher magnitude than GCA variance for all the traits. Besides this the ratio of σ^2_{sca} / σ^2_{gca} was greater than one for all the traits indicating the preponderance of non-additive gene effects in the expression of these traits. These results are in accordance with the findings of Motamedi *et al.* (2014) [17] and Ruswandi *et al*. (2015) [23]. Estimates of GCA effects of the parents and SCA effects of the hybrids for different traits are presented in Table 5 and 6. Only one inbred line UDMI-206 (-1.35) showed negative significant GCA effects for days to 50 per cent pollen shedding. Among the testers, only one tester (V-351) showed significant negative GCA effects (-0.81). The significant negative SCA effects for days to 50 per cent pollen shedding were exhibited by four hybrids with the magnitude varing from -3.92 (UDMI-136 x HKI-1105) to -2.08 (UDMI-206 x V-351). One inbred line expressed negative significant GCA effect for days to 75 per cent brown husk with magnitude -6.54 (UDMI-206). The significant negative SCA effects for days to 75 per cent brown husk were exhibited by only one hybrid (UDMI-134 x V-351) with the magnitude of -7.07. Out of seven inbred lines, only one inbred line expressed negative significant GCA effects for plant height with magnitude -13.86 (UDMI-134) while, among the testers, only one tester (HKI-1105) showed significant negative GCA effects (-11.23) for plant height. The significant negative SCA effects for plant height were exhibited by two hybrids with the magnitude of -19.26 (UDMI-143 x V-351) and -18.80 (UDMI-206 x V-341). The estimates of GCA effects revealed that only one inbred line expressed positive significant GCA effects for test weight with magnitude 10.51 (UDMI-206) while, among the testers, only one tester (V-351) showed significant positive GCA effects for this trait with a magnitude of 7.27. The significant positive SCA effects for test weight were exhibited by two hybrids with the magnitude of 16.97 (UDMI-205x HKI-1105) and 17.18 (UDMI-215x V-351). For grain yield per plant, the maximum positive significant SCA effects were depicted by hybrid UDMI-205 x V-341 (10.70) followed by hybrid UDMI-205x HKI-1105(10.18) and hybrid UDMI-134x V-351 (9.91). Among the parents, two inbred lines expressed positive significant GCA effects for grain yield per plant with magnitude varying from 9.33 (UDMI-206) to 13.33 (UDMI-136), while only one tester (V-351) showed significant negative GCA effects (10.76) for grain yield per plant.

Similar finding for identification of superior inbred lines and hybrids based on GCA and SCA effects for grain yield and its components in maize were also reported by Jebaraj *et al.* (2010) [10], Kanagarasu *et al.* (2010) [11], Lal *et al.* (2011) [16], Reddy *et al.* (2011) [22], Guimaraes *et al.* (2012) [7], Patil *et al.* (2012) [20], Mural and Chikkalingaiah (2012) [18], Panwar *et al.* (2013), Singh *et al.* (2013) [24], Izhar and Chakraborty (2013) [8], Jahan *et al.* (2014) [9], Motamedi *et al.* (2014) [17] and Kumar *et al.*(2015a) [14].

In the present investigation, the magnitude of standard heterosis (Table 7) revealed that thirteen hybrids showed negative significant standard heterosis which ranged from -15.38 (UDMI-143 x V-351) to -5.92 per cent (UDMI-206 x V-351). Hybrids which depicted maximum negative significant standard heterosis were UDMI-143 x V-351 (-15.38) followed by UDMI-215 X HKI-1105 (-14.79), UDMI-143 x HKI-1105, UDMI-143 x V-341 and UDMI-136 x V-351 (-11.24) per cent for this trait over the hybrid check *viz.* PHM-12. The estimates of standard heterosis pointed out that twenty hybrids out of twenty-one showed negative significant standard heterosis over the hybrid check *viz.* PHM-12 for days to 50 per cent silking, two hybrids out of twenty-one showed negative significant standard heterosis for days to 75 per cent brown husk and only hybrid UDMI-134x HKI-1105 (-7.54) exhibited negative significant standard heterosis for plant height. Sixteen hybrids depicted positive significant standard heterosis for this trait with magnitude ranged from 10.00 (UDMI-135 x V-351) to 93.64 (UDMI-135 X V-341) per cent over the hybrid check. The maximum positive significant economic heterosis was depicted by hybrid UDMI-135 X V-341(93.64%) UDMI-143x V-351 (92.99%) followed by hybrid UDMI-205Xv-341 (87.91%) and UDMI-206x HKI-1105 (70.14%) and can exploited for developing single cross hybrids. Ruswandi *et al.* (2015) [23], Khan *et al.* (2016) [13] and Bharti *et al.* (2017) [5] also reported standard heterosis in maize for yield and its contributing traits.

Table 1: Description of inbred lines involved in the study

S. No.	Inbred lines	Pedigree
1	HKI-1105	HKI-1105-2-2/Cargil633
2	V341	Mexico Acc. No. 3136 F □-3-2-3-8-1-□b-#-□b-#-□b##
3	V351	Shakti(So)HE25
4	UDMI-134	CAO3118-1
5	UDMI-135	P31C4S5B-85-##-1-4-5-BBB-B-B-3
6	UDMI-136	P31C4S5B-85-##-1-4-5-BBB-B-B-B-2
7	UDMI-143	P31C4S5B-79-##-7-B-B-B-B
8	UDMI-205	WNCDMR11R0144
9	UDMI-206	WNCDMR11R0144A
	UDMI-215	WNCDMR10RYFWS8384

UDMI- Udhampur maize inbred

Table 2: Analysis of variance of inbred lines and hybrids for different quantitative traits in maize

Source of variation	d.f	Days to 50% Pollen Shed	Days to 50% Silking	Days to 75% Brown Husk	Plant Height	Test Weight	Grain yield per plant
Replication	2	6.84	32.33	308.65**	2430.92**	368.3	153.84**
Progeny	30	15.43**	4.61	87.14**	957.44 **	859.70 **	595.55**
Parents	9	17.07**	4.03	71.01**	1074.82**	177.1	237.72**
Parents (tester)	2	9.33*	3.44	3.52	301.59	11.44	382.33**
Parents (lines)	6	16.77**	4.53	70.02*	1400.50*	256.1	197.65*
Parents (L vs T)	1	34.30**	2.17	211.93**	667.13	33.83	188.92
Crosses	20	14.70**	4.68*	91.14**	866.64**	799.65 **	644.06**
Parents vs. Crosses	1	15.43*	8.56	152.32*	1717.01**	8204.04 **	2845.7**
Error	60	2.94	3.3	24.19	181.31	165.12	66.46

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

Table 3: Analysis of variance of crosses for combining ability for different quantitative traits in maize

Source of variation	d.f	Days to 50% Pollen Shed	Days to 50% Silking	Days to 75% Brown Husk	Plant Height	Test Weight	Grain yield per plant
Replication	2	7.04	19.87**	371.52**	1587.34**	752.11*	23.28 **
F_1 hybrids	20	14.7	4.68	91.15**	866.64**	799.65 **	644.07 **
Inbreds	6	5.65	5.42	103.39	408.73	770.62	954.63 *
Testers	2	11.76	2.21	150.34	3921.75*	1226.73	1824.33 *
Testers x inbreds	12	19.72**	4.72	75.17**	586.42**	742.99 **	292.07 **
Error	40	2.78	3.77	22.41	202.43	201.26	65.45

*, ** Significant at 5% and 1% level, respectively

Table 4: Estimates of components of variance for combining ability

Components of genetic variance	Days to 50% pollen shed	Days to 50% Silking	Days to 75% Brown Husk	Plant Height	Test Weight	Grain yield per plant
σ^2_L	0.32	0.18	9	22.92	63.26	98.8
σ^2_t	0.43	-0.07	6.09	177.11	48.83	83.76
σ^2_{GCA}	0.39	0.03	6.96	30.85	53.16	75.54

σ^2_{SCA}	5.65	0.32	17.58	127.99	180.58	88.27
$\sigma^2_{SCA}/\sigma^2_{GCA}$	14.3	113.32	2.53	4.15	3.4	1.16
σ^2_D	0.78	0.06	13.92	61.7	106.32	151.08
σ^2_H	11.3	0.64	35.16	255.98	361.16	176.54

Table 5: Estimate of general combining ability effects of lines and testers for different characters in maize

Lines and testers	Days to 50% Pollen Shed	Days to 50% Silking	Days to 75% Brown Husk	Plant Height (cm)	Test Weight (gm)	Grain yield per plant (gm)
UDMI-134	0.21	-0.35	1.18	-13.86 **	-0.16	-3
UDMI-135	0.98	1.43 *	0.7	-1.92	-16.38 **	0.22
UDMI-136	-0.13	-1.02	2.51	3.73	5.62	13.33 **
UDMI-143	0.1	-0.13	2.07	-0.53	5.84	-2.11
UDMI-205	-0.57	0.18	2.66	1.65	2.51	-18.89 **
UDMI-206	-1.35 *	-0.46	-6.54 **	5.57	10.51 *	9.33 **
UDMI-215	0.76	0.1	-2.57	5.35	-7.94	1.11
S.E.gi (line)	0.56	0.65	1.58	4.74	4.72	2.7
S.E.gi-gj (line)	0.79	0.92	2.23	6.71	6.68	3.81
HKI-1105	0.14	-0.11	1.96	-11.23 **	-7.97 *	-5.29 **
V-341	0.67	0.37	1.09	15.21 **	0.7	-5.48 **
V-351	-0.81 *	-0.25	-3.05 **	-3.98	7.27*	10.76 **
S.E.gi(tester)	0.36	0.42	1.03	3.1	3.09	1.77
S.E.gi-gj(tester)	0.51	0.6	1.46	4.39	4.37	2.5

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

Table 6: Estimates of Specific combining ability effects of crosses for different traits in maize

Cross combinations	Days to 50% Pollen Shed	Days to 50% Silking	Days to 75% Brown Husk	Plant Height (cm)	Test Weight (gm)	Grain Yield per plant (gm)
UDMI-134 X HKI-1105	-0.59	-1.22	-0.51	-14.61	-11.37	-4.05
UDMI-135X HKI-1105	-3.03 **	-1	-1.23	-10.92	12.52	-5.6
UDMI-136X HKI-1105	-3.92 **	-0.89	-4.81	-11.98	3.19	-4.71
UDMI-143X HKI-1105	1.86	0.89	-1.5	5.82	-7.37	-0.27
UDMI-205X HKI-1105	0.86	-0.81	0.81	11.32	16.97 *	10.18 *
UDMI-206X HKI-1105	3.30 **	1.22	4.61	12.52	-3.03	8.29
UDMI-215X HKI-1105	1.52	1	2.63	7.85	-10.92	-3.83
UDMI-134 X V-341	2.22 *	0.97	7.58 **	9.47	15.3	-5.86
UDMI-135X V-341	1.44	1.52	3.63	1.23	10.52	-3.08
UDMI-136X V-341	1.22	0.64	-3.58	10.94	-12.81	4.81
UDMI-143X V-341	-2.67 **	-1.92	1.46	13.44	8.64	-5.75
UDMI-205X V-341	-0.67	0.81	-2.33	-4.74	-23.03 **	10.70 *
UDMI-206X V-341	-1.22	-0.59	-4.39	-18.80 *	7.64	-4.86
UDMI-215X V-341	-0.33	0.19	-2.37	-11.53	-6.25	4.03
UDMI-134 X V-351	-1.64	0.25	-7.07 *	5.14	-3.94	9.91 *
UDMI-135X V-351	1.59	-0.52	-2.4	9.69	-23.05 **	8.68
UDMI-136X V-351	2.70 **	0.25	8.39 **	1.04	9.62	-0.1
UDMI-143X V-351	0.81	1.03	0.04	-19.26 *	-1.27	6.02
UDMI-205X V-351	-0.19	0.43	1.52	-6.58	6.06	-20.87 **
UDMI-206X V-351	-2.08 *	-0.64	-0.22	6.28	-4.6	-3.43
UDMI-215X V-351	-1.19	-1.19	-0.26	3.69	17.18 *	-0.21
S.E.(sij)	0.96	1.12	2.73	8.21	8.19	4.67
S.E.sij-skl	1.36	1.59	3.87	11.62	11.58	6.61

*, ** Significant at 5% and 1% level, respectively

Table 7: Estimate of percent heterosis over standard check for different quantitative characters in maize

Cross combinations	Days to 50% Pollen Shed	Days to 50% Silking	Days to 75% Brown Husk	Plant Height (cm)	Test Weight (gm)	Grain Yield per plant (gm)
UDMI-134 X HKI-1105	-8.28**	-10.06**	6.3	-7.54*	-12.30*	-21.17**
UDMI-135X HKI-1105	-5.91	-5.59*	14.15**	13.70*	2.19	-23.01**
UDMI-136X HKI-1105	-7.04**	-7.82**	-6.26	1.37	-3.01	6.44
UDMI-143X HKI-1105	-11.24**	-6.70*	4.99	-4.59	-9.15	-19.63**
UDMI-205X HKI-1105	-2.37	-10.05	9.34*	15.63*	-6.42	-17.48**
UDMI-206X HKI-1105	-7.73	-6.15*	-5.53	10.01	-17.49**	12.27*
UDMI-215X HKI-1105	-14.79**	-10.61**	3.08	-2.18	-3.96	-6.75
UDMI-134 X V-341	-4.73	-7.26**	3.47	23.69**	-6.97	1.84
UDMI-135X V-341	-4.73	-5.59**	2.20**	20.54	4.92	23.30*
UDMI-136X V-341	-4.14	-6.15*	6.19	4.91	-8.2	-16.87**
UDMI-143X V-341	-11.24**	-10.06**	8.47*	22.76**	1.91	-22.09**

UDMI-205X V-341	-7.69**	-6.15*	2.42	-4.43	0.55	3.68
UDMI-206X V-341	-7.10**	-6.70*	9.34*	8.93	0.41	-22.70**
UDMI-215X V-341	-8.88**	-7.26**	4.99	14.38**	-12.43*	-22.39**
UDMI-134 X V-351	-10.65**	-5.59**	4.67	3.35	2.19	-18.10**
UDMI-135X V-351	-4.14	-6.15*	3.47	11.62	-4.51	1.53
UDMI-136X V-351	-11.24**	-8.38**	0.35	9.07	3.42	-10.74
UDMI-143X V-351	-15.38**	-9.50**	-3.94*	12.15*	1.09	5.52
UDMI-205X V-351	-3.55	-5.59*	5.65	9.06	-15.30**	-12.57**
UDMI-206X V-351	-5.92*	-6.15*	-0.72	12.76*	-9.84*	-10.12
UDMI-215X V-351	-10.06**	-9.50**	-2.93	10.68	2.46	0.92
S.E.	0.57	0.57	8.73	10.08	6.61	0.49

*, ** Significant at 5% and 1% level, respectively

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Author contribution
Bupesh Kumar and Ashish Sheera designed the study; Kavita Raina, Ashok Kumar Razdan, wrote the first draft, all authors participated in the data collection, elaborated and analyzed the data and critically revised the manuscript.

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