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Elucidation of combining ability and gene action in maize [*Zea mays* (L.)]

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Abstract
Maize (*Zea mays* L.) is an important monoecious plant with imperfect flowers. Due to its maximum genetic production potential, a study was conducted to determine the best genotype based on combining ability. The experimental material was made up of 8 parents, their 28 crosses (excluding reciprocal) from an 8 × 8 diallel mating design, and one standard check (GDYMH 101). At the Maize Research Station, Sardarkrushinagar Dantiwada Agricultural University, Bhiloda, the experiment was set up using a randomised block design with three replications to study fourteen characters *viz.,* days to tasseling and silking, anthesis silking interval, plant height, ear height, days to maturity, cob length, cob girth, kernel rows per cob, kernels per row, kernel yield per plant, shelling percentage, 100-kernel weight and protein content in seed. The analysis of variance for experimental design revealed significant mean square values of genotypes for all the variables indicated existence of considerable amount of genetic variations. Comparison of mean squares due to parents *vs* hybrids and check *vs* hybrids found to be highly significant for most of the traits. Due consideration should be given to heterosis as the analysis of variance of combining ability demonstrated the predominance of non-additive gene action in the expression of kernel yield per plant and the majority of examined traits. Also, hybrids BLD 255 × WNC 32804 and BLD 255 × BLD 134 displayed higher kernel yield per plant in performance. Estimates of GCA effect revealed that, parent BLD 138 was found good general combiner for kernel yield per plant and other characters *viz.,* anthesis silking interval, kernel rows per cob, kernels per row, shelling percentage and 100-kernel weight. While, the parent BLD 134 had favourable genes for flowering traits. The estimates of SCA effects showed that top three hybrids *viz.,* BLD 255 × WNC 32804, BLD 255 × BLD 134 and BLD 255 × WNC 52346 were exhibited maximum positive significant SCA effect for kernel yield per plant and other contributing traits. Thus, best specific combiners should be exploited to develop commercially high yielding hybrids.

Keywords: Maize, general combining ability, gene action, diallel

Introduction

Maize (*Zea mays* L., 2 n = 20) is one of the most versatile crops having wider adaptability under varied agro-climatic conditions. It is a member of the grass family *Poaceae*, tribe *Maydeae* and one of the oldest cultivated crops (Sleper and Poehlman, 2006) [1]. Due to its high starch, protein, oil, and sucrose content compared to other cereals, maize has grown significantly in industrial significance. In a variety of industries, including the manufacturing of alcohol, textiles, paper, medicines, cosmetics, edible oil, chicken feed, and many chemical ones, maize and its primary byproducts, starch, syrup, glucose, gluten, and oil, are employed. Currently, nearly 1147.7 million tonnes of maize is being produced together by over one hundred seventy countries from an area of 193.7 million ha with average productivity of 5.75 tonnes per ha (Anonymous, 2020) [4]. Maize breeding systems mostly require hybridization, genotype assessment, and selection of suitable genotypes (s). To produce a competitive, cost-effective hybrid maize variety, heterosis and good combining ability are necessary (Krivanek *et al.* 2007) [2]. Maize, along with rice and wheat, provides at least 30 per cent of food calories to over 4.5 billion people in 94 developing nations (Shiferaw *et al.*, 2011) [3].

Combining ability refers to the capacity or ability of a genotype to transmit superior performance to its crosses. Sprague and Tatum (1942) [9] in maize proposed the concept of combining ability as a measure of gene action and from their results Sprague and Tatum (1942) [9] concluded that the general combining ability was mainly the results of additive gene action while the specific combining ability due to dominance, epistasis and genotypic environment interaction. Diallel analysis which involves the crossing of all lines in all possible combinations is an efficient method for the study of combining ability and also the gene action of the characters under study. (Kumar and Babu 2016) [5].

Combining ability analysis is of special importance in cross-pollinated crops like maize as it helps in identifying potential parents that can be used for producing hybrids and synthetics

The present study was undertaken to estimate the combining ability of parents and hybrids and hence the nature and magnitude of gene action for yield and yield components in 8 x 8 diallel analysis at Maize Breeding Station, Bhiloda, Gujarat, India.

Materials and Methods

Eight maize inbred lines *viz*., BLD 256, BLD 130, BLD 255, WNC 32804, BLD 138, WNC 52346, BLD 253 and BLD 134 were crossed in diallel fashion excluding reciprocal during the Rabi season of 2021-22. A field trial was conducted involving all the 28 single crosses, their 8 parents and one check (GDYMH 101) during kharif 2022 in Randomized Block Design with three replications at Maize Research Station, Bhiloda, S.D. Agricultural University, Gujarat, India. The plot length was 4 m and inter and intra row spacing was 60 × 20 cm. The observations were recorded on days to tasseling, days to silking, anthesis silking interval, plant height, ear height, days to maturity, cob length, cob girth, kernel rows per cob, kernels per row, kernel yield per plant, shelling percentage, 100 kernel weight and protein content. Data were recorded from five randomly selected plants from each block. General and specific combining ability analysis were performed using Griffing's procedure Method-I, Model II (Griffing, 1956) [8].

Results and Discussion

The analysis of variance revealed significant differences among all the genotypes for all the characters under study. Further partition of genotype showed that, parents differed significantly for all the characters except for the days to tasseling, days to silking, anthesis silking interval, days to maturity and cob length. It indicated the presence of sufficient amount of genetic variability in the material under study. While, the analysis of variance due to hybrids were found significant for all the traits under study except anthesis silking interval, which indicated that the genetic variation was existing in hybrids. The variance due to parents *vs*. hybrids found significant for all the characters under study except anthesis silking interval, cob girth, shelling percentage and protein content. which suggested the existence of difference between parents and hybrids. Mean sum of squares due to check *vs* hybrids were significant for the characters like; days to silking, anthesis silking interval, plant height, ear height, cob girth, kernel yield per plant and protein content only, which indicated lesser different between check and hybrids for remaining traits. (Table 1)

Table 1: Analysis of variance for characters under study in maize

Source of variation	d.f.	Days to tasseling	Days to silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Cob length	Cob girth	Kernel rows per cob	Kernels per row	Kernel yield per plant	Shelling percentage	100-kernel weight	Protein content
Replications	2	5.86	2.82	0.39	41.59	5.22	1.36	4.92	0.50	0.56	14.00	261.32	6.48	10.30	0.02
Genotypes (G)	36	9.58**	10.00**	0.48*	624.67**	159.68**	9.15**	5.15**	1.55**	1.30**	33.72**	553.12**	17.01**	19.82**	0.06**
Parents (P)	7	3.14	3.23	0.52	436.67**	105.40**	3.24	1.01	0.84**	3.67**	52.20**	980.99*	27.28**	9.28*	0.06**
Hybrids (H)	27	6.77**	6.46**	0.36	688.55**	155.82**	6.2**	5.14**	1.70**	0.68**	11.46**	294.68**	15.07*	19.25**	0.05**
Parents *vs.* Hybrids	1	137.52**	150.48**	0.29	701.65**	785.78**	138.73**	39.25**	0.92	2.15**	539.05**	3995.50**	13.59	128.62**	0.00
Check *vs.* Hybrids	1	2.60	12.67*	3.79**	138.89**	17.70*	0.60	0.19	3.20**	0.53	0.17	1093.43**	1.02	0.32	0.21**
Error	72	2.55	2.30	0.27	16.51	3.12	2.43	1.662	0.26	0.23	5.43	118.57	8.75	3.80	0.01

Variances for general combining ability and specific combining ability along with gene action for different traits in maize is presented in Table 2. GCA and SCA variance were found significant for all the characters under study except, anthesis silking interval and cob length. This result indicated that both additive and non additive gene effects were important for inheritance of characters under study. For cob length, only SCA variance was significant indicating role of only non- additive gene action. While in case of anthesis silking interval, GCA and SCA variance were non-significant therefore, there may be a role of environment in governing of this trait. The ratio of σ^2GCA/σ^2SCA for all the characters under study was found less than unity. Therefore, prime role of non-additive gene action was observed for inheritance of all the traits. So, exploitation of these traits for improvement of yield through heterosis breeding may be beneficial. Similar findings were reported by Mogesse *et al.* (2020) [10] for days to tasseling, days to silking, ear height, cob length, cob girth, kernel rows per cob and kernels per row. Matin *et al.* (2016) [11] for anthesis silking interval. Lal and Kumar (2012) [12] for plant height and days to maturity. Patel *et al*. (2019) [13] for yield and other contributing traits.

Table 2: Analysis of variance (mean sum of square) for combining ability, estimates of components of variance and their ratio for various characters in maize

Source of variation	d.f.	Days to tasseling	Days to silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Cob length	Cob girth	Kernel rows per cob	Kernels per row	Kernel yield per plant	Shelling percentage	100-kernel weight	Protein content
GCA	7	2.41*	2.06*	0.16	101.28**	35.92**	2.34*	0.97	0.46**	0.99**	19.42**	183.30**	8.33*	11.50**	0.02**
SCA	28	3.47**	3.62**	0.12	240.74**	59.24**	3.33**	1.96**	0.51**	0.30**	9.60**	178.21**	5.20*	5.62**	0.02**
Error	70	0.86	0.78	0.09	5.62	1.04	0.82	0.57	0.09	0.08	1.86	40.64	2.96	1.30	0.00
σ2GCA		6.77**	0.15*	0.13*	0.007	9.57**	3.49**	0.15*	0.04	0.04**	0.09**	1.76**	14.27**	0.54*	1.02**
σ2SCA		137.52**	2.61**	2.84**	0.03	235.12**	58.20**	2.51**	1.39**	0.42	0.22**	7.74**	137.57**	2.24*	4.32**
σ2GCA/σ2SCA		2.60	0.06	0.05	0.23	0.04	0.06	0.06	0.03	0.09	0.41	0.23	0.10	0.24	0.24

The general combining ability (*gca*) effects of eight parents and the specific combining ability (*sca*) effects of 28 hybrids for yield and yield contributing characters were estimated and were presented in Tables 3 and 4 respectively. Parents with negative GCA effect are considered as best for days to tasseling and days to silking because earliness is desirable trait in maize. Parental line BLD 134 was found good general combiner for days to tasseling (-0.58) and silking (-0.71). Among all the parental genotypes under study, parent BLD 138 was recorded as good general combiner for kernel yield per plant (7.63). BLD 138 was also found promising for other traits like anthesis silking interval (-0.19), kernel rows per cob (0.28), kernels per row (1.25), shelling percentage (1.53) and 100-kernel weight (1.47). For the cob girth, BLD 255 (0.34) and BLD 134 (0.22) was found good general combiner. Parents BLD 255 (0.21), WNC 32804 (0.23) and BLD 138 (0.28) were found good general combiners for kernel rows per cob. Parental lines BLD 138 (1.25), BLD 134 (1.39) and BLD 253 (1.51) were also recorded as good general combiner for kernels per row. Among all the parents, WNC 32804 (0.05) and BLD 253 (0.06) was recorded as good general combiner for protein content. These parents have resulted in the production of superior single cross hybrids. Hence these parental genotypes could be utilised in future breeding programmes for exploitation of hybrid vigor and also to generate a greater number of desirable segregants for kernel yield and yield attributing characters. These results are comparable with findings of Suthamathi and Nallathambi (2016) [14] for cob length, cob girth, kernel rows per cob, kernels per row and kernel yield per plant. Mogesse *et al.* (2020) [10] for days to tasseling, days to silking and ear height. Patel *et al.* (2019) [13] for yield and other contributing traits.

Table 3: Estimates of general combining ability (*gca*) effects of parents for yield and yield component characters in maize

Parents	Days to tasseling	Days to silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Cob length	Cob girth	Kernel rows per cob	Kernels per row	Kernel yield per plant	Shelling percentage	100-kernel weight	Protein content
BLD 256	-0.32	-0.14	0.18	-5.49**	-3.88**	-0.11	-0.37	-0.14	-0.64**	-2.32**	-1.62	-1.02*	-0.83*	0.02
BLD 130	-0.22	-0.21	0.01	1.38	0.62*	-0.18	-0.50*	0.09	-0.28**	-0.77	-3.16	-0.25	-1.30**	-0.05*
BLD 255	0.42	0.36	-0.06	-1.76*	-0.15	0.36	0.28	0.34**	0.21*	-1.30**	-2.92	0.32	0.50	0.00
WNC 32804	0.32	0.43	0.11	-2.46**	-0.25	0.39	0.01	-0.30**	0.23**	0.36	-5.49**	0.55	-0.83*	0.05*
BLD 138	0.88**	0.69*	-0.19*	1.11	-0.12	0.73**	0.05	-0.13	0.28**	1.25**	7.63**	1.53**	1.47**	0.01
WNC 52346	-0.15	-0.18	-0.02	4.31**	3.05**	-0.08	0.28	0.06	0.11	-0.14	-0.47	-1.01	-0.47	-0.03
BLD 253	-0.35	-0.24	0.11	3.14**	0.45	-0.28	-0.09	-0.14	0.12	1.51**	2.54	-0.74	1.53**	0.06**
BLD 134	-0.58*	-0.71**	-0.13	-0.23	0.28	-0.84**	0.35	0.22*	-0.03	1.39**	3.49	0.62	-0.07	-0.06**
S.E. (gi)	0.27	0.26	0.09	0.70	0.301	0.27	0.22	0.09	0.08	0.40	1.89	0.51	0.34	0.02

Hybrid BLD 138 × BLD 134 (-3.24) had negative significant SCA effects for the character, which was desirable for days to tasselling. The hybrids, BLD 138 × BLD 134 (-2.40) and WNC 52346 × BLD 253 (-1.67) had significant negative estimates of SCA effect hence considered as good specific cross combinations for days to silking. The cross BLD 138 × WNC 52346 (-0.59) considered good specific combiner followed by BLD 255 × WNC 32804 (-0.52) for anthesis silking interval. Negative direction was favoured in plant height for short plant stature to avoid lodging. For plant height, twelve cross registered significant and negative SCA effects. Crosses WNC 32804 × BLD 253 (-11.33), BLD 138 × BLD 134 (-9.30) and BLD 253 × BLD 134 (-8.80) showed negative estimates of SCA effects that suggested good specific combining ability for the ear height. Top two single cross hybrids were BLD 138 × BLD 134 (-2.34) and WNC 52346 × BLD 253 (-1.77) for days to maturity. The combinations *viz.*, BLD 256 × BLD 134 (2.47), BLD 256 × BLD 130 (2.44), BLD 130 × BLD 253 (2.04) and BLD 255 × BLD 134 (1.85) were found superior specific combiners for cob length. The cross BLD 255 × WNC 32804 (1.8) possessed highest SCA effect in desired direction for cob girth followed by the crosses BLD 256 × BLD 134 (1.54), BLD 255 × BLD 134 (1.15) and BLD 256 × BLD 130 (0.97). Out of 28 crosses, 4 crosses recorded significant and positive SCA effect for the kernel rows per cob. The cross BLD 130 × WNC 52346 (4.62) possessed maximum SCA effect followed by the crosses BLD 130 × BLD 253 (4.36) and BLD 255 × BLD 134 (3.72) for kernels per row. The hybrids, BLD 255 × WNC 32804 (34.83) followed by BLD 255 × BLD 134 (18.8) and BLD 255 × WNC 52346 (17.79) showed positive estimates of SCA effects and become good specific combiners for kernel yield per plant. The crosses, BLD 138 × WNC 52346 (4.28), BLD 255 × BLD 134 (3.90), BLD 130 × BLD 253 (3.12), BLD 256 × WNC 52346 (2.87) and WNC 52346 × BLD 253 (2.83) showed positive estimates of SCA effects suggesting to be good specific combiner for shelling percentage. The crosses, BLD 138 × BLD 253 (5.00), WNC 52346 × BLD 253 (3.93) and BLD 255 × BLD 134 (2.90) showed positive estimates of SCA effects and considered as good specific combiners for 100-kernel weight. Based on the significant and positive SCA effect the crosses BLD 130 × BLD 138 (0.23), BLD 255 × BLD 138 (0.23) and BLD 256 × WNC 32804 (0.21) were found best specific cross combinations for protein content. The crosses exhibiting high *per se* performance may results from either good × good, good × average, average × average and poor × poor general combining parents. The good general combining parents when crossed do not always produce high SCA effects, while poor general combining parents not always produce low SCA effects. So, any parental combination may result into high SCA effects. These results were similar with findings of Suthamathi and Nallathambi (2016) [14], Mogesse *et al.* (2020) [10] and Patel *et al.* (2019) [13] for yield and other contributing traits.

Table 4: Estimates of specific combining ability (*sca*) effects for single crosses for yield and yield component characters in maize

Hybrids	Days to tasseling	Days to silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Cob length
BLD 256 × BLD 130	-0.41	-0.40	0.01	-9.99**	-6.86**	-0.50	2.47**
BLD 256 × BLD 255	0.29	0.37	0.08	-5.19**	4.90**	0.30	-1.30*
BLD 256 × WNC 32804	-0.28	-0.03	0.24	3.51	2.34**	-0.07	-0.63
BLD 256 × BLD 138	-0.18	-0.30	-0.12	-2.72	4.54**	-0.40	-0.93
BLD 256 × WNC 52346	0.52	0.23	-0.29	0.08	2.04*	0.73	-0.42
BLD 256 × BLD 253	1.39	1.30	-0.09	33.58**	5.64**	1.26	-0.27
BLD 256 × BLD 134	1.96**	1.77*	-0.19	-11.05**	-3.86**	1.83*	2.47**
BLD 130 × BLD 255	1.52*	1.43*	-0.09	29.61**	10.40**	1.36	-0.73
BLD 130 × WNC 32804	-0.38	-0.30	0.08	-4.02*	-0.16	-0.34	-0.57
BLD 130 × BLD 138	1.39	1.43*	0.04	-6.59**	0.37	1.33	-2.64**
BLD 130 × WNC 52346	1.76*	1.97**	0.21	35.21**	13.54**	2.46**	0.63
BLD 130 × BLD 253	-0.04	0.03	0.08	-10.95**	4.14**	0.00	2.04**
BLD 130 × BLD 134	1.19	1.17	-0.02	1.08	1.97*	1.23	0.22
BLD 255 × WNC 32804	-0.01	-0.53	-0.52*	8.45**	3.94**	-0.54	1.77**
BLD 255 × BLD 138	1.76*	1.53*	-0.22	5.21**	1.47	1.46*	1.23*
BLD 255 × WNC 52346	1.46	1.40*	-0.06	-0.32	0.30	1.26	1.40*
BLD 255 × BLD 253	0.32	0.80	0.48*	-23.49**	-8.76**	0.80	-0.04
BLD 255 × BLD 134	2.89**	3.27**	0.38	6.88**	5.40**	2.36**	1.85**
WNC 32804 × BLD 138	2.52**	3.13**	0.61*	20.25**	11.24**	3.10**	1.17
WNC 32804 × WNC 52346	1.89*	2.00**	0.11	5.71**	10.07**	1.90**	0.42
WNC 32804 × BLD 253	0.76	1.07	0.31	-13.12**	-11.33**	1.10	0.59
WNC 32804 × BLD 134	-0.01	-0.13	-0.12	8.25**	3.17**	0.00	-0.39
BLD 138 × WNC 52346	0.32	-0.27	-0.59*	-6.85**	-7.06**	-0.44	0.65
BLD 138 × BLD 253	0.86	0.47	-0.39	-7.02**	-3.46**	0.43	1.01
BLD 138 × BLD 134	-3.24**	-2.40**	0.84**	-13.65**	-9.30**	-2.34**	-0.40
WNC 52346 × BLD 253	-1.44	-1.67*	-0.22	-3.22	5.04**	-1.77*	-0.45
WNC 52346 × BLD 134	-1.21	-0.87	0.34	-18.52**	-8.13**	-0.87	0.17
BLD 253 × BLD 134	1.32	1.20	-0.12	16.98**	8.80**	1.33	-0.29
S.E.(Sij) ±	0.73	0.70	0.24	1.87	0.80	0.71	0.60

Hybrids	Cob girth	Kernel rows per cob	Kernels per row	Kernel yield per plant	Shelling percentage	100-kernel weight	Protein content
BLD 256 × BLD 130	0.97**	0.42	1.53	12.68*	1.56	1.80*	-0.05
BLD 256 × BLD 255	-0.56*	0.06	2.99**	-12.78*	2.30	-1.33	-0.12*
BLD 256 × WNC 32804	-0.53*	0.24	1.67	-3.09	1.62	1.00	0.21**
BLD 256 × BLD 138	-0.37	0.92**	0.71	0.54	-2.29	1.37	-0.07
BLD 256 × WNC 52346	0.02	-0.04	0.10	2.77	2.87*	-1.70	0.10
BLD 256 × BLD 253	-0.17	0.28	2.45*	10.25*	-0.39	0.30	0.00
BLD 256 × BLD 134	1.54**	0.03	1.84	13.13*	-2.52	1.90*	-0.12*
BLD 130 × BLD 255	-0.23	0.10	-0.43	1.37	0.72	1.13	-0.04
BLD 130 × WNC 32804	-0.41	-0.32	2.12	4.04	-1.27	0.13	0.03
BLD 130 × BLD 138	-0.18	0.96**	-1.11	5.67	0.53	-3.5**	0.23**
BLD 130 × WNC 52346	-0.40	-0.34	4.62**	1.67	-0.45	0.77	-0.08
BLD 130 × BLD 253	0.17	0.46	4.36**	10.56*	3.12*	-0.23	0.07
BLD 130 × BLD 134	0.16	-0.06	0.82	5.16	-3.52*	-0.63	-0.04
BLD 255 × WNC 32804	1.80**	-0.02	2.31*	34.83**	-2.94*	1.00	-0.06
BLD 255 × BLD 138	-0.46	0.07	0.42	-13.62**	-0.41	0.70	0.23**
BLD 255 × WNC 52346	0.79**	-0.43	2.81*	17.79**	-1.63	-0.03	0.07
BLD 255 × BLD 253	-0.44	0.10	-0.04	-0.25	-1.77	1.63	-0.03
BLD 255 × BLD 134	1.15**	-0.16	3.72**	18.80**	3.90**	2.90**	0.10
WNC 32804 × BLD 138	-0.25	-0.88**	1.23	-2.56	0.27	-0.63	0.09
WNC 32804 × WNC 52346	-0.04	-0.58*	0.69	0.68	1.34	-0.70	0.02
WNC 32804 × BLD 253	-0.27	0.08	-1.63	-2.20	-0.25	0.63	-0.12*
WNC 32804 × BLD 134	0.09	0.49*	-0.37	0.47	1.68	-0.77	0.19**
BLD 138 × WNC 52346	-0.05	0.30	1.13	2.28	4.28**	-0.67	-0.15*
BLD 138 × BLD 253	-0.07	0.03	2.54*	3.24	-2.91*	5.00**	-0.29**
BLD 138 × BLD 134	-0.61*	0.04	0.67	-13.30*	0.41	-0.40	-0.07
WNC 52346 × BLD 253	0.15	0.06	0.27	-5.37	2.83*	3.93**	-0.08
WNC 52346 × BLD 134	-0.12	-0.46	-0.81	7.02	-1.43	0.53	-0.13*
BLD 253 × BLD 134	-0.29	0.74**	-1.19	-8.73	-0.35	2.20*	0.17**
S.E.(Sij) ±	0.24	0.23	1.08	5.03	1.36	0.90	0.06

Conclusion

This study found that the inbred lines BLD 138 and BLD 134 have significant yield-contributing features and strong general combining ability impacts for yield. These parents had resulted in the production of superior single crosses. Hence, these inbred lines can be considered as potential parents for future breeding programmes. The estimates of sca effects revealed that the cross combinations crosses BLD 255 × WNC 32804, BLD 255 × BLD 134, BLD 255 × WNC 52346, BLD 256 × BLD 134 and BLD 256 × BLD 130 were observed most promising hybrids with high specific combining ability effects for grain yield and some of its attributes. These hybrids can be created as commercial hybrids, progressed for selfing to isolate transgressive segregants or homozygous lines for use in breeding programmes, and tested in many places for multi-locations trail.

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