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Combining ability of selected quality protein maize (*Zea mays* L.) parental lines under normal and heat stress combination

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Abstract

Background: Maize (*Zea mays* L.) is an essential food source for humans and cattle all over the globe. It has a great yield potential and leads the cereal industry in terms of both output and productivity. However, the nutritional quality of maize protein is regarded low, since typical maize "Zein" protein comprises on average approximately 2% lysine, which is less than half of the concentration necessary for human nutrition.

Methods: In *Rabi* 2018, a diallel mating set of 7 newly developed QPM inbred lines was used for crossing, and evaluation for combining ability for yield and its component traits was done in *Kharif* 2019 and *Spring* 2020 at the Field Experimentation Centre, Department of Genetics and Plant Breeding, SHUATS, Prayagraj (Allahabad).

Result: The analysis of variance due to general combining ability (GCA) and specific combining ability (SCA) was significant for all characters except anthesis silking interval and canopy temperature deficit. The parent VL-1016556 was revealed to be a useful general combiner for grain yield and character attributes. P_1xP_2, P_1xP_3, P_1xP_6, and P_1xP_7 crosses all had significant SCA effects on grain yield per plant. These four crosses may be further utilized for the development of superior hybrids after confirming their consistency in Allahabad agro-climatic conditions.

Keywords: Quality protein maize, general combining ability, specific combining ability, grain yield per plant

Introduction

Maize (*Zea mays* L.) is India's third most valuable food crop (Murdia *et al*., 2016; Yadav and Gangwar, 2021) [10, 21]. It has grown significantly as a result of increased demand for feed, industrial use, and food (Tilman *et al*., 2011; Murdia *et al*., 2016) [19, 10]. Just about half of all maize produced is used as a raw material in the poultry feed industry (Rajitha *et al*., 2014) [4]. Maize is known as the "Queen of Cereals" because it has the highest genetic yield potential of any cereal (Dass *et al*., 2012) [3]. Given that maize is grown in a very distinct natural environment in our country, we prioritise the development of high-yielding hybrids with built-in tolerance and resistance to a variety of climatic stresses, pests, and diseases, as well as the development and fine-tuning of production ecology. Despite its numerous applications, maize has the additional problem of being deficient in two essential amino acids, namely lysine and tryptophan (Maqbool *et al*., 2021) [8]. Vasal and Beck (1990) [20] developed the concept of quality protein maize (QPM) at CIMMYT (International Centre for Maize and Wheat Improvement, Mexico), for which they shared the World Food Prize in 2000. As an outcome, traditional maize genotypes have low net protein utilization and nutritive value. To fill this gap, maize breeders developed QPM by incorporating the opaque-2 (Mertz *et al*., 1964; Maqbool *et al*., 2021) [9, 8] mutant gene, which is crucial for stimulating the lysine and tryptophan content of maize endosperm protein (Bajaj *et al*., 2007; Darshan and Marker, 2019) [1-2]. The current maize production is 21.7 million tonnes, with an average productivity of 2.5 tonnes per acre (Gurjar *et al*., 2022) [5].

The principle of combining ability has developed in prominence in maize breeding, as well as in other crops (Sharma *et al*., 2019) [16]. Sprague and Tatum (1942) [17] proposed General Combining Ability (GCA) and Specific Combining Ability (SCA) (SCA). GCA variance is proportional to additive variance, while SCA variance is related to non-additive variance, according to them. Griffing (1956) [4] introduced their mathematical modelling in conjunction with the diallel crosses in his classic paper, and both serve as significant analytical tools in the evaluation of optimal parents and cross combinations.

Commercial maize hybrid improvement often requires a thorough grasp of the breeding materials to be used's combining potential. In the present research, the selection of parents based on combining ability was employed as a key breeding technique in crop development.

Materials and Methods

The experimental materials used in this study included seven selected inbred lines: VL-1016556 (CIMMYT, Mexico), CML-171 (CIMMYT, Mexico), BHU-N5 (BHU, Varanasi), BHU QPM-3 (BHU, Varanasi), BHU-N6 (BHU, Varanasi), CML-161 (CIMMYT, Mexico), and KL-153237 (CIMMYT, Mexico). The trials were carried out at the Field Experimentation Centre of the Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology, and Sciences, Prayagraj (Allahabad), Uttar Pradesh. In the *Rabi* season of 2018-2019, seven inbred lines were grown and crossed using a half-diallel mating design to yield 21 single crosses. The 21 F_1s, along with their parents and a control, HQPM-5, were grown in *Kharif* 2019 and *spring* 2020, followed by data collection on 16 characters (quantitative and physiological). The collected data were subjected to analysis of variance as proposed by Panse and Sukhatme (1961) [12] and combining ability as proposed by Sprague and Tatum (1942) [17].

Result and Discussion

In both the *Kharif* 2019 and *Spring* 2020 seasons, the analysis of variance due to general combining ability (GCA) and specific combining ability (SCA) was significant for all characters except anthesis silking interval and canopy temperature deficit (Table 2). The significance of both the GCA and SCA components of variance indicates the role of both additive and non-additive gene action in the inheritance of these traits. Therefore, these traits can be improved through population improvement methods, which include genetic modification, synthetics, and composites, or through breeding. For all the characters studied, however, the magnitude of SCA effects was significantly larger than that of GCA effects (GCA/SCA<1). This indicates that non-additive genetic effects predominate in their inheritance (Seshu *et al*., 2010) [15]. Sharma *et al*. (2019) [16] revealed consistent results in a quality protein maize crop for the LxT (9x7) crossing design in 12 characters. Murtadha *et al*. (2018) [11] derived comparable outcomes in the maize crop by using the non-reciprocal diallel crossing design with six parents in eight characters.

General Combining ability (GCA) and Specific combining ability (SCA)

Table 2. Shows the effects of GCA of parents and SCA of hybrids. A parent's high general combining ability indicates its ability to combine well with other parental figures, including the presence of additive gene effects for that trait (Sprague and Tatum, 1942) [17]. Table 4. (*Kharif* 2019) and Table 5. (*Spring* 2020) exhibit the estimates of the SCA effect.

Among the parents, the line BHU-N6 demonstrated a significant negative GCA effect in *Kharif* 2019 for days to 50% tasseling and days to 50% silking and was found to be the best combiner for earliness to tasseling and silking. In *Kharif* 2019, the crosses P_1xP_7 and $P_{2X}P_5$, and even more commonly in *spring* 2020, the crosses P_4xP_7, showed negative significant SCA effects for days to 50% tasseling, indicating that these crosses were good specific combiners for days to 50% tasseling and days to 50% silking. Gurjar *et al*. (2022) [5] in maize and Sharma *et al*. (2019) [16] in QPM promote equality by promoting negative GCA and SCA effects for days to 50% tasseling and days to 50% silking.

In *Kharif* 2019, the parent BHU-N5 and the crosses P_2xP_4, P_3xP_7 seemed to have significant negative GCA and SCA effects for the anthesis silking interval. Both Murthada *et al*. (2018) [11] and Gurjar *et al*. (2022) [5] discovered that GCA and SCA had a negative effect on the anthesis silking interval in maize crops.

For plant height, the parents VL-1016556, CML-171, and KL-153237 exhibited significant negative GCA effects in *Kharif* 2019, and similarly, parent VL-1016556 exhibited significant negative GCA effects in *spring* 2020, indicating that the above-mentioned parents were the best dwarfness combiners. Crosses between P_1xP_5 and P_3xP_5 seemed to have negative, significant SCA effects on plant height in *Spring* 2020. The findings are similar to study results in QPM by Bajaj *et al*. (2007) [1] and Sharma *et al*. (2019) [16]. Premlatha and Kalamani (2010) [13] and Gurjar *et al*. (2022) [5] both reported negative GCA and SCA effects on plant height in maize crops.

In *Kharif* 2019, the parent, KL-153237, exhibited a significant positive GCA effect, and in *Spring* 2020, the parents, BHU QPM-3 and CML-161, exhibited positive significant GCA effects and can be considered the best combiner for plant girth. The P_4xP_5 cross had quite a significant positive SCA effect in both seasons. Premlatha and Kalamani (2010) [13] reported similar findings for plant girth in the maize crop.

The parents, VL-1016556 and BHU-N5, exhibited positive significant GCA effects in *spring* 2020 and proved to be excellent combiners for leaf area index. The crosses P_1xP_4 and P_3xP_6 seemed to have a significant positive SCA effect in both seasons. Murthada *et al*. (2018) [11] noticed positive GCA for LAI in maize crops as well.

The parents found significant negative GCA effects for cob height in Kharif 2019, VL-1016556, CML-171 and KL-153237, and in *Spring* 2020, VL-1016556, which turned out to be the best combiner for low cob placement. SCA effects analysis reported that two cross combinations of P_1xP_7, P_2xP_4 seemed to have negative significant SCA effects on cob height in *Kharif* 2019. Darshan and Marker (2019) [2] and Sharma *et al*. (2019) [16] observed significant negative GCA and SCA effects in QPM.

The parent VL-1016556 was the best combiner for cob length and cob girth in *Kharif* 2019 and *spring* 2020, with a significant positive GCA effect P_1xP_2, P_1xP_3, P_1xP_4, P_4xP_5, and P_6xP_7 crosses had a significant positive SCA effect for cob length and girth in *Kharif* 2019 and *spring* 2020. Similarly, Subramanian and Subbaraman (2006) [18] and Gurjar *et al*. (2022) [5] in maize, Bajaj *et al*. (2007) [1], and Lahane *et al*. (2015) [7] in QPM noticed positive significant GCA and SCA effects for cob length and cob girth in their respective fields of study.

The parent, VL-1016556, was found to have a significant positive GCA effect and to be a good combiner for cob weight in *Kharif* 2019 and *spring* 2020. An assessment of SCA effects found that four cross combinations of P_1xP_2, P_1xP_3, P_1xP_6 and P_1xP_7 exhibited positive, significant SCA effects for cob weight in Kharif 2019 and spring 2020. These outcomes for cob weight were comparable to those of Lahane *et al*. (2015) [7] in QPM for both GCA and SCA effects.

For the number of kernel rows per cob parent VL-1016556 in *Kharif* 2019 and KL-153237 in *spring* 2020 showed positive, significant GCA impacts and proved to be the best combiners. In both *Kharif* 2019 and *spring* 2020, SCA effects for the number of kernel rows per cob revealed that cross P_1xP_3 was the best cross. In maize, Kanagarasu *et al*. (2010) [6] and Gurjar *et al*. (2022) [5] reported similar GAC and SCA effects for the number of kernel rows per cob, as also Darshan and Marker (2019) [2] in QPM.

In *Kharif* 2019, the parent, VL-1016556, revealed significant positive GCA results and revealed to be the superior combiner for the number of kernels per row. P_1xP_2, P_1xP_6, P_3xP_7 and P_4xP_5 are the ideal crosses for *Kharif* 2019 and *spring* 2020. Both Subramanian and Subbaraman (2006) [18] and Kanagarasu *et al*. (2010) [6] identified significant GCA and SCA effects in maize crops for the number of kernels per row.

In *Kharif* 2019, and more typically in *spring* 2020, the parents, VL-1016556 and BHU-N5, displayed positive GCA impacts and proved to be the top combiners for 100 seed weight. In *Kharif* 2019 and *spring* 2020, the crosses P_1xP_3, P_1xP_6, P_1xP_7, P_2xP_5, P_2xP_7, P_4xP_5 and P_4xP_7 exhibited positive significant SCA effects for 100 seed weight. Gurjar *et al*. (2022) [5] found similar GCA and SCA effects in maize, as well as Bajaj *et al*. (2007) [1] and Sharma *et al*. (2019) [16] in QPM.

In *Kharif* 2019, the parent, VL-1016556, and the parents, VL-1016556 and CML-171 in *spring* 2020, exhibited positive significant GCA effects and constituted the best combiners for grain yield per plant. As an outcome, these parents might be used for the hybridization programme to select superior recombinants. In both *Kharif* 2019 and *spring* 2020, the crosses P_1xP_2, P_1xP_3, P_1xP_6 and P_1xP_7 displayed positive significant SCA effects. This predominance of non-additive gene action implies that this trait may be improved through population improvement methods including selection, intermixing among chosen ones, and reselection, in addition to using heterosis-exploiting breeding approaches. Gurjar *et al*. (2022) [5] discovered positive substantial GCA and SCA impacts in maize, as did Bajaj *et al*. (2007) [1], Sharma *et al*. (2019) [5], and Darshan and Marker (2019) [2] in QPM crop.

The GCA/SCA variance ratio was <1, showing the existence of non-additive gene action for controlling these traits, and breeding procedures such as selection, intermingling among the selected ones, reselection, and heterosis breeding may contribute to improving these traits. This indicated that dominant alleles were more prevalent in parents than recessive alleles. This has the potential to be used in the development of early maturing hybrids in QPM.

Table 1: List of parents and hybrids

S. No.	Notation	Genotype	S. No.	Notation	Genotype
1	P1	VL-1016556	15	P_2xP_4	CML-171 X BHU QPM-3
2	P2	CML-171	16	P_2xP_5	CML-171 X BHU-N6
3	P3	BHU-N5	17	P_2xP_6	CML-171 X CML-161
4	P4	BHU QPM-3	18	P_2xP_7	CML-171 X KL-153237
5	P5	BHU-N6	19	P_3xP_4	BHU-N5 X BHU QPM-3
6	P6	CML-161	20	P_3xP_5	BHU-N5 X BHU-N6
7	P7	KL-153237	21	P_3xP_6	BHU-N5 X CML-161
8	P_1xP_2	VL-1016556 X CML-171	22	P_3xP_7	BHU-N5 X KL-153237
9	P_1xP_3	VL-1016556 X BHU-N5	23	P_4xP_5	BHU QPM-3 X BHU-N6
10	P_1xP_4	VL-1016556 X BHUQPM-3	24	P_4xP_6	BHU QPM-3 X CML-161
11	P_1xP_5	VL-1016556 X BHU-N6	25	P_4xP_7	BHU QPM-3 X KL-153237
12	P_1xP_6	VL-1016556 X CML-161	26	P_5xP_6	BHU-N6 X CML-161
13	P_1xP_7	VL-1016556 X KL-153237	27	P_5xP_7	BHU-N6 X KL-153237
14	P_2xP_3	CML-171 X BHU-N5	28	P_6xP_7	CML-161 X KL-153237

Table 2: Analysis of variance for combining ability for different parameters in in Quality Protein Maize in two seasons (*Kharif*-2019 and *Spring*-2020)

S. No.	Character	Mean Sum of Squares					
		Kharif 2019			Spring 2020		
		Var-GCA	Var-SCA	Error	Var-GCA	Var-SCA	Error
		6	21	54	6	21	54
1	Days to 50% tasseling	2.91*	3.77**	1.03	4.59*	4.96**	2.02
2	Days to 50% silking	2.58*	3.62**	1.13	4.96*	4.78**	1.96
3	Anthesis-silking interval	0.15	0.11	0.07	0.09	0.07	0.12
4	Plant height	529.18**	623.18**	35.36	182.88**	403.60**	36.94
5	Plant girth	0.76**	0.51**	0.11	0.45**	0.66**	0.08
6	Leaf area index	0.05	0.18**	0.04	0.52**	0.16**	0.01
7	Chlorophyll content	1.33	11.71**	2.23	12.24*	19.48**	4.50
8	Canopy temperature deficit	0.05	0.06	0.07	0.02	0.12	0.09
9	Cob height	113.57**	84.40**	4.32	53.06*	43.88**	21.80
10	Cob length	1.40**	1.28**	0.07	1.21	1.99**	0.08
11	Cob girth	1.19**	1.03**	0.04	0.48**	0.75**	0.10
12	Cob weight	143.28**	116.32**	65.64	35.84**	118.74**	3.34
13	Number of kernel rows per cob	0.42	0.53**	0.23	0.14**	0.16**	0.04
14	Number of kernels per row	0.76	4.83**	0.37	0.30	2.46**	0.16
15	100 seed weight	3.04**	2.74**	0.27	2.03**	3.81**	0.11
16	Grain yield per plant	137.56**	119.55**	15.79	33.34**	120.06**	3.21

**Significant at 1% and *Significant at 5% level of significance respectively

Table 3: General Combining Ability effects of parents for different parameters in Quality Protein Maize (*Kharif*-2019 and *Spring*-2020)

	***Kharif* 2019**							***Spring* 2020**						
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
X_1	-0.03	-0.33	0.78*	0.41	-0.99**	-0.07	0.22	0.81	0.29	-0.64	-0.6	-0.75	-0.12	0.10*
X_2	-0.01	-0.19	0.6	0.55	-1.04**	-0.01	0.18	0.73	0.29	-0.64	-0.46	-0.86	-0.2	1.14*
X_3	0.00	0.15	-0.22*	0.07	0.00	0.11	-0.11	-0.1	-0.02	0.02	0.16	-0.1	-0.06	0.09
X_4	-10.24**	-3.84*	0.56	0.43	3.86*	13.98**	-4.77*	-6.60**	-0.01	-2.86	6.21**	4.73*	-2.77	1.3
X_5	-0.32**	0.07	-0.06	0.11	-0.41**	0.18	0.43**	-0.18*	-0.36**	0.08	0.22*	0.14	0.21*	-0.12
X_6	0.06	-0.04	0.05	0.04	0.07	-0.11	-0.07	0.47**	-0.05**	0.11**	-0.02**	-0.14**	-0.07**	-0.30**
X_7	-0.28	0.16	-0.06	-0.08	0.62	-0.58	0.23	0.09	1.67*	-0.78	0.85	0.78	-1.29	-1.32*
X_8	-0.07	-0.03	-0.03	0.16	0.04	-0.02	-0.05	-0.05	-0.02	0.01	0.07	-0.02	0.05	-0.03
X_9	-2.42**	-3.46**	2.38**	0.77	-0.27	6.35**	-3.35**	-3.04*	-0.18	-2.63	-0.92	1.04	3.54*	2.18
X_{10}	0.77**	0.11	-0.18*	0.11	-0.12	-0.48**	-0.20*	0.63**	0.31**	-0.07	0.02	-0.16	-0.44**	-0.30**
X_{11}	0.78**	0.11	-0.21**	-0.13	-0.15*	-0.23**	-0.18**	0.49**	-0.03	-0.12	0.04	-0.07	-0.21*	-0.11
X_{12}	5.90*	-3.15	2.08	-1.04	-1.12	-0.74	-1.93	3.79**	1.67**	-0.8	-1.07	-1.44*	-0.54	-1.62**
X_{13}	0.38*	0.16	0.06	-0.25	-0.15	-0.12	-0.09	0.07	0.1	-0.19**	0.00	-0.12*	-0.02	0.16**
X_{14}	0.48*	-0.2	-0.06	0.29	-0.36	0.01	-0.17	0.24	0.05	0.02	-0.04	-0.30*	0.18	-0.14
X_{15}	1.10**	-0.15	0.38*	-0.42*	0.03	-0.33*	-0.61**	0.68**	0.33**	0.25*	-0.23*	0.05	-0.32**	-0.75**
X_{16}	8.20**	-0.15	1.31	-2.16	-2.21	-1.93	-3.08*	3.41**	1.89**	-0.34	-1.02	-1.52**	-0.63	-1.78**

**Significant at 1% and *Significant at 5% level of significance respectively

X_1: Days to 50% tasseling; X_2: Days to 50% silking; X_3: Anthesis-silking interval; X_4: Plant height; X_5: Plant girth; X_6: Leaf area index; X_7: Chlorophyll content; X_8: Canopy temperature deficit; X_9: Cob height; X_{10}: Cob length; X_{11}: Cob girth; X_{12}: Cob weight; X_{13}: Number of kernel rows per cob; X_{14}: Number of kernels per row; X_{15}: 100 seed weight; X_{16}: Grain yield per plant.

Table 4: Specific Combining Ability effects of crosses for different parameters in Quality Protein Maize (*Kharif*-2019)

S. No.	Notation	X1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
1	P_1xP_2	0.41	-0.10	-0.48	23.31**	0.18	0.06	-0.03	-0.09	6.36**	0.90**	0.80**	14.22**	-0.01	3.91**	0.30	14.41**
2	P_1xP_3	-1.37	-1.51	-0.44	-2.76	-0.86**	-0.26	-2.2	0	0.71	0.91**	1.22**	11.56**	1.42**	-1.23*	1.07*	9.16*
3	P_1xP_4	-2.00*	-1.81	0.26	6.84	0.26	0.54**	-0.48	0.35	-0.24	1.26**	0.87**	4.60	0.40	1.10	-0.14	5.52
4	P_1xP_5	-1.59	-1.58	0.33	10.18	0.04	0.23	-0.99	0.24	14.96**	0.69*	0.60**	-0.28	0.29	-0.26	-0.38	-0.39
5	P_1xP_6	0.82	1.05	-0.11	1.15	0.08	0.00	2.76	-0.04	3.81	0.85**	0.91**	11.39**	-0.40	2.04**	1.85**	10.53**
6	P_1xP_7	-3.15**	-2.81**	0.44	29.14**	1.38**	0.84**	-2.84*	0.06	-6.10**	0.87**	0.80**	12.89**	0.23	0.22	3.59**	14.89**
7	P_2xP_3	-1.07	-0.99	0.41	7.81	1.25**	0.66**	4.81**	-0.3	10.59**	0.51*	0.56**	0.98	0.31	-1.22*	0.88	0.86
8	P_2xP_4	-0.37	-0.62	-0.56*	35.74**	-0.50	0.13	-1.97	-0.09	-6.75**	0.06	0.15	-0.75	-0.05	0.11	-0.39	-1.43
9	P_2xP_5	-2.96**	-2.73**	0.19	5.51	0.22	0.14	-5.67**	0.3	3.80	0.23	0.70**	-5.06	-0.69	-0.58	1.07*	-2.86
10	P_2xP_6	-1.89	-1.77	0.07	-2.18	0.18	0.05	-6.07**	-0.15	3.85	0.55*	0.52*	0.41	-0.17	1.05	-0.44	0.72
11	P_2xP_7	0.48	0.71	0.30	12.47*	0.20	-0.12	0.27	0	-1.99	0.44	0.53*	5.91	0.46	-1.11	1.81**	5.19
12	P_3xP_4	-0.48	-0.03	0.48	16.81**	-0.42	0.02	-1.59	-0.32	10.66**	0.14	0.75**	4.80	1.25**	-1.37*	0.05	4.06
13	P_3xP_5	0.26	0.19	-0.11	22.35**	0.04	0.20	-0.5	0.33	3.99*	0.27	0.12	0.72	-0.06	-0.06	0.33	1.01
14	P_3xP_6	-1.00	-0.84	0.11	12.62*	-0.04	0.49*	-2.3	0.16	2.48	-0.21	-0.49*	4.68	-1.01*	2.57**	1.49**	6.06
15	P_3xP_7	-1.30	-2.03**	-0.67*	24.34**	0.16	-0.05	-4.55**	0.32	9.48**	0.85**	0.07	7.43	-0.85	4.75**	-0.26	7.59*
16	P_4xP_5	0.63	0.57	-0.07	3.31	1.07**	-0.56**	-3.28*	-0.15	0.81	1.06**	0.40*	11.27**	-0.68	3.94**	0.99*	10.77**
17	P_4xP_6	-0.96	-0.81	0.15	-4.68	0.14	-0.12	2.22	0.07	2.26	-0.05	-0.13	1.68	-0.17	0.23	0.66	1.70
18	P_4xP_7	-1.26	-1.32	0.04	9.91	0.84**	0.35	3.62*	0.1	3.99*	-0.4	0.00	2.56	0.26	-0.59	1.41**	4.03
19	P_5xP_6	0.11	0.08	-0.11	2.96	-0.18	0.39*	-0.98	-0.08	5.12*	0.34	0.37	5.16	1.40**	-1.79**	0.61	5.16
20	P_5xP_7	0.82	0.57	-0.22	-6.86	0.36	-0.30	1.16	0.09	0.38	0.23	-0.11	-0.97	0.49	-0.95	-0.44	-1.52
21	P_6xP_7	-0.11	0.19	0.33	16.52**	-0.52	-0.19	-0.64	0.14	6.81**	0.99**	0.51*	-0.92	0.27	0.68	-1.38**	-1.23

**Significant at 1% and *Significant at 5% level of significance respectively

X_1: Days to 50% tasseling; X_2: Days to 50% silking; X_3: Anthesis-silking interval; X_4: Plant height; X_5: Plant girth; X_6: Leaf area index; X_7: Chlorophyll content; X_8: Canopy temperature deficit; X_9: Cob height; X_{10}: Cob length; X_{11}: Cob girth; X_{12}: Cob weight; X_{13}: Number of kernel rows per cob; X_{14}: Number of kernels per row; X_{15}: 100 seed weight; X_{16}: Grain yield per plant.

Table 5: Specific Combining Ability effects of crosses for different parameters in Quality Protein Maize (*spring*-2020)

S. No.	Notation	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
1	P_1xP_2	-0.65	-0.69	-0.32	19.63**	0.36	-0.22**	-0.41	-0.19	1.62	0.95**	0.82**	9.93**	0.07	2.42**	0.30	8.69**
2	P_1xP_3	-2.06	-2.10	-0.03	14.14*	-1.26**	0.34**	-4.06*	0.33	3.84	0.56*	1.64**	9.06**	0.35*	0.46	1.31**	7.58**
3	P_1xP_4	0.57	0.71	0.16	11.88*	0.34	0.38**	-0.79	0.3	1.87	1.38**	0.95**	7.19**	0.30	1.85**	0.20	8.11**
4	P_1xP_5	-0.61	-0.55	0.08	-11.77*	1.62**	0.29**	-2.42	0.45	8.97*	0.98**	0.41	4.34*	0.29	-0.23	1.18**	4.40*
5	P_1xP_6	-1.91	-1.88	0.05	16.78**	1.33**	0.04*	-5.25*	-0.18	-4.93	1.29**	0.12	9.28**	0.32	1.29**	0.79*	8.35**
6	P_1xP_7	6.98**	6.79**	-0.10	10.91	-0.25	-0.09**	3.78	-0.21	5.42	0.59*	-0.06	4.66**	-0.06	-0.39	2.78**	6.80**
7	P_2xP_3	-0.20	0.34	0.57	15.49**	-0.24	-0.24**	1.46	-0.51	2.77	1.79**	-0.02	7.73**	0.32	0.31	1.56**	7.64**
8	P_2xP_4	-0.24	-0.18	0.08	-2.97	0.67*	0.02	-3.01	-0.14	-4.17	0.17	-0.12	4.19*	0.40*	0.70	-0.25	3.62*
9	P_2xP_5	-2.43	-2.44	0.01	11.03	0.07	0.32**	-6.40**	0.44	9.17*	0.28	0.18	3.73*	0.52**	-0.38	1.40**	6.18**

10	P_2xP_6	0.28	-0.10	-0.36	29.33**	-0.11	0.61**	0.91	-0.02	1.14	0.52	0.22	3.08	-0.12	1.48**	0.07	3.54*
11	P_2xP_7	1.50	1.57	0.16	2.86	-0.50	0.62**	-2.57	0.39	6.30	0.55*	0.92**	7.53**	0.10	0.80*	1.29**	7.07**
12	P_3xP_4	-0.65	-0.92	-0.29	14.28*	-0.79**	-0.24**	-2.02	0.41	6.52	0.35	0.44	5.41**	-0.18	0.41	1.49**	4.49*
13	P_3xP_5	-0.50	-0.84	-0.36	-19.82**	0.42	-0.55**	-6.48**	-0.01	-6.85	0.19	0.24	4.62*	0.21	0.66	0.61	4.83**
14	P_3xP_6	-0.13	0.16	0.27	4.28	0.59*	0.17**	-1.74	0.13	6.87	-0.14	-0.45	3.51*	0.17	-0.82*	2.08**	4.74**
15	P_3xP_7	-1.91	-1.84	0.12	-2.66	0.57*	0.50**	2.32	0.34	-1.05	1.06**	-0.2	1.96	-0.08	0.83*	0.10	2.05
16	P_4xP_5	-0.54	-0.36	0.16	3.32	1.12**	0.45**	2.59	-0.04	-1.25	1.14**	0.62*	1.41	-0.78**	1.05**	1.06**	0.98
17	P_4xP_6	1.83	1.97	0.12	0.88	-0.74**	-0.30**	-3.08	0.2	0.12	-0.02	0.25	1.12	-0.02	0.24	0.30	1.33
18	P_4xP_7	-2.94*	-3.03*	-0.03	11.68*	0.39	-0.27**	-0.78	0.24	2.17	-0.06	0.28	3.49*	0.21	-0.11	1.32**	5.01**
19	P_5xP_6	-0.02	0.38	0.38	13.02*	-0.16	-0.27**	-2.4	-0.09	5.69	0.49	0.35	7.73**	0.17	0.83*	1.35**	7.62**
20	P_5xP_7	-1.13	-0.95	0.23	-6.38	-0.21	0.39**	-2.27	0.16	3.84	0.38	-0.24	5.39**	0.12	1.15**	0.04	4.09*
21	P_6xP_7	-1.43	-1.29	0.19	14.88*	-0.68*	-0.12**	-1.00	0.2	3.18	1.12**	0.83**	4.10*	0.42*	1.34**	-0.69*	3.88*

**Significant at 1% and *Significant at 5% level of significance respectively

X_1: Days to 50% tasseling; X_2: Days to 50% silking; X_3: Anthesis-silking interval; X_4: Plant height; X_5: Plant girth; X_6: Leaf area index; X_7: Chlorophyll content; X_8: Canopy temperature deficit; X_9: Cob height; X_{10}: Cob length; X_{11}: Cob girth; X_{12}: Cob weight; X_{13}: Number of kernel rows per cob; X_{14}: Number of kernels per row; X_{15}: 100 seed weight; X_{16}: Grain yield per plant.

Conclusion

In both the Kharif and spring seasons, the analysis of variation due to general combining ability (GCA) and specific combining ability (SCA) was significant for all characteristics except the anthesis silking interval and canopy temperature deficit. Combining ability analysis found that for maximal characteristics under investigation in both *Kharif* and *Spring*, estimations of SCA variations were larger than GCA variances, showing the dominance of non-additive gene activity for trait expression. The parent VL-1016556 was discovered to be an excellent general combiner for grain yield and character attribution. P_1xP_2, P_1xP_3, P_1xP_6 and P_1xP_7 crosses all had substantial SCA impacts on grain yield per plant. After proving to be stable in Allahabad's agro-climatic conditions, the parent VL-1016556 and four crosses may be utilised to create superior hybrids.

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