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Combining ability studies for physiological and yield traits in maize (*Zeamays* L.) across three environments

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ABSTRACT

The present study was conducted to assess the general combining ability effects of parents and specific combining ability effects of crosses for yield and yield contributing traits in maize hybrid development. Combining ability studies were conducted in10 X 10 half diallel fashion at Prayagraj to determine GCA and SCA effects of parents and single crosses respectively. The economic heterosis (hc) revealed that the hybrids CM-124 x LM-13, HKI-193-2 x CM 129, DMR-QPM-28 x CM- 124, HKI-193-2 x POP 445 and CML 41 x POP 445 showed positive significant results across the three environments E1, E2 and E3. The combining ability study indicated that the parents, HKI-193-2 (P_{10})LM 13(P_6) and line CM 129 (P_5) can be considered as good general combiners and genetically worthy parents, as they contributed favourable genes for grain yield. The parent CML- 41 (P_9) was a good general combiner for the trait chlorophyll content in all three environments, while the parent LM 13 (P_6) was a good source for favourable alleles for leaf area index since they had significant positive gca effects.The parents HKI-193-2 (P_{10})LM 13(P_6)can be considered as good general combiners for protein content.The pooled analysis of variance over three environments revealed the mean sum of squares due to genotypes was significant for the characters studied. The hybrid CM- 124 x LM-13 showed good specific combining ability effects for grain yield,days to 50 % tasseling, days to 50 % silking, days to 50% maturity, 100 seed weight, chlorophyll content, leaf relative water content, leaf area index, leaf area ratio and protein content.The hybrid HKI-193-2 x CM 129 showed good specific combining ability effects for grain yield, days to 50% maturity, one hundred seed weight, leaf area index, leaf area ratio and starch content.

Key words: Combining ability, grain yield, maize, economic heterosis (hc)

INTRODUCTION

Maize (Zea mays L.) being a C_4 plant and fertilizer responsive has very high yielding ability coupled with higher amount of cross pollination which offers tremendous scope for the plant breeders for genetic improvement. Among cereals, maize is rich in starch, proteins, oil and sucrose, due to which it has assumed significant industrial importance. Its main by-products viz., starch, syrup, glucose, gluten and oil are used in diversified industries like alcohol production, textile, paper, pharmaceuticals, cosmetic industry, edible oil industry, poultry feed and many chemical industries. Maize oil obtained from germ of kernel is rich in polyunsaturated fatty acids and also contains high level of natural anti-oxidants, hence maize oil is ideal for heart patients. The main goal of maize breeding is to obtain new hybrids with high genetic potential for yield and positive features that exceed the existing commercial hybrids. The commercial production of hybrids however, depends upon two factors viz., the behavior of the line itself and the behavior of line in hybrid combination. The chlorophyll content is an important trait which indicates the photosynthetic potential which affects the photosynthetic activity and capability of the plant tissues. The stay-green leaf phenotype is typically associated with increased yields and improved stress resistance in maize breeding, due to higher nitrogen levels that prolong greenness. If the chlorophyll content is high, there is a higher photosynthetic activity or rather capturing activity of the photosynthetic radiation. The chlorophyll measurements are done through non-destructive methods by the Minolta SPAD-502 chlorophyll meter. The leaf relative water content is a physiological trait that helps in understanding the leaf hydration status for adaptation to water stress. The area of the leaf lamina or all green surfaces (leaf lamina, leaf sheath, stem and spike) of the crop relates to the light interception and photosynthetic potential, the surfaces for transpiration/water loss, and the aboveground biomass of the crop.Leaf area index is a measure of leafiness per unit of ground area and the extent of

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photosynthetic machinery which accounts to the ability of the crop to capture light energy. Combining ability analysis is an important method to evaluate the prepotency of cultures to be used in breeding programme and to assess the gene action involved in various characters so as to design an appropriate and efficient breeding method. Combining ability analysis provides this information and is frequently used by plant breeders to choose parents with a high general combining ability and hybrids with high specific combining ability effects. Variance for GCA is associated with additive genetic effects, while that of SCA includes non-additive genetic effects, arising largely from dominance and epistatic deviations with respect to certain traits. In a systematic breeding program, it is essential to identify superior parents for hybridization and crosses to expand the genetic variability for selection of superior genotypes. Combining ability is a useful biometric tool to the plant breeders for formulating an efficient breeding program. (Jebaraj et al 2010).In the present study, an attempt has been made to assess the combining ability for physiological and yield traits across environments.

MATERIALS AND METHODS

The experimental materials were generated by making crosses between 10 parental lines in a half diallel mating design (Griffing, 1956).The 10 parents (Early yellow(P1), POP- 445 (P2), POP-31 Q2 (P3),CML -359 (P4), CM 129 (P5), LM 13 (P6), CM- 124 (P7),DMR-QPM28(P8), CML-41(P9) andHKI-193-2 (P10), 45 F_1s, and 3 checks *viz;*K-25, GA-85 and Navjyot were evaluated in Kharif 2016 in three environments E_1, E_2 and E_3, which were created by different dates of sowing (E_1-1st July, E_2-15thJuly and E_3-31st August) with an interval of 15 days between the environments was sown at SHUATS, Prayagraj.The experiment was laid out in the randomized block design with three replications. The recommended package of practices was followed to raise a healthy crop. The recommended N:P:K dose applied was 120:60:60 kg ha^{-1}, where in the full dose of phosphorus and potassium was applied at sowing while the nitrogen dose was applied half at the sowing and the other half was applied in split doses and was top dressedat knee height stage. The chlorophyll content was recorded with the help of Minolta SPAD-502 chlorophyll meter. The protein content was estimated following the method developed by Lowry et al (1951).The estimation of starch content was done with the Anthrone reagent and subsequently readings were taken at 630 nm in an Ultra Violet Spectrophotometer. The oil content was estimated in the maize flour following the AOAC method (1975).The analysis of variance was done according by Panse and Sukhatme (1967). The statistical analysis for estimation of heterosis was done according to Turner (1953). The data were recorded on parents and their F1s were subjected to combining ability analysis following the procedure proposed by Griffing (1956)-Experimental Method-II and Model-I (Fixed effects) with an assumption that there were no reciprocal differences.

RESULTS AND DISCUSSION

Pooled Analysis of variance for combining ability

The mean sum of squares due to environments were significant for the characters days to 50 %tasseling, 50 % silking, 50% maturity, plant height, cob length, grain rows/cob, grains/ row, chlorophyll, leaf relative water content, flag leaf area/ plant and leaf area ratio (Table 1). Mean sum of squares due to genotypes were significant for all the characters. Similarly, mean sum of squares due to interaction were also significant for all the characters except for anthesis-silking interval, ear height and cobs per plant, 100 seed weight, biological yield, harvest index, starch,protein and oil content.Similar trends for variance and its components in maize were also reported byReddy *et al.* (2015) and BharathiveEraman *et al*. (2016).

General combining ability effect in maize parents across environments

Results (Table 1) revealed that the parents, Early yellow (P_1) and line POP- 445 (P_2) were found as good general combiners in all three environments E_1, E_2 and E_3 for earliness in tassel The *gca* effect for days to 50% tasseling were observed to vary from -0.91** (Early yellow) to -0.66** (POP -31 Q2) in E_1, from-1.38** (Early yellow) to -0.47** (POP -31 Q2) in E_2, and from -1.01** (Early yellow and POP-445) to -0.23 (CML -359 and CM- 124) in E_3.Similar results were observed by Kumar *et al.*(2022) and

Yazachew *et al.* (2017). Results on *gca* effects revealed that the two lines Early yellow (P_1) and line POP- 445 (P_2) exhibited good general combiners in all three environments.The *gca* effect for days to 50% silking were observed to vary from -0.88** (Early yellow) to -0.69** (POP -31 Q2) in E_1, from-1.43** (Early yellow) to-0.48** (POP -31 Q2) in E_2, and from -1.07** (Early yellow) to -0.23 (CML -359) in E_3**.**Similar results were observed by Kumar *et al.* (2022). General combining ability results revealed that Early yellow (P_1), line POP- 445 (P_2) showed significant desirable negative *gca* effects for days to 50% maturity in all environments while line POP -31 Q2 (P_3) showed negative *gca* effect in E_2 and E_3 respectively.The*gca* effect for days to 50% maturity were observed to vary from -1.43** (Early yellow) to -0.68* (CML -359) in E_1, from-1.78** (Early yellow) to -0.96* (POP- 445) in E_2, and from -2.12** (Early yellow) to -1.62** (POP -31 Q2) in E_3. The results were supported by the findings of Kumar *et al.* (2022). From the general combining ability study, the parents HKI-193-2 (P_{10})LM 13(P_6) and line CM 129 (P_5) were found to be good general combiners of this trait as they exhibited significant positive *gca* effects in environments.The *gca* effect for grain yield per plant varied from 0.45 (CM- 124) to 8.52** (LM 13) in E_1, from 0.89 ** (DMR QPM-28) to 7.35 ** (LM 13) in E_2, and from 0.44 ** (POP- 445) to 5.97 **(LM 13) in E_3. The results were supported by the findings of Sumalini *et al.* (2015) and Kumar *et al.* (2022). Study on *gca* effects reveal that the parental line HKI-193-2 (P_{10})showed significant positive *gca* effects in all environments, while the line LM 13 (P_6) and POP- 445 (P_2) in environments E_1 and E_2 making them as suitable good combiners for the trait. The *gca* effect for 100 kernel weight varied from 0.78** (POP -31 Q2) to 2.09** (HKI-193-2) in E_1, from 0.58** (POP -31 Q2) to 2.22** (HKI-193-2) in E_2, while it varied from 0.75 (POP -31 Q2) to 2.15** (HKI-193-2) in E_3. Similar results were reported by Sandesh *et al.*(2018) and Chavan *et al.*(2019).

Table 1 Pooled analysis of variance for agro-morphological characters in maize (*Zea mays* L.)

Sources of variation	Mean sum of squares				
	Env (df = 2)	Rep (df = 6)	Genotype (df = 57)	G×E Interaction (df = 114)	Error (df = 342)
Days to 50% Tasseling	513.43**	5.34	20.05**	3.30**	0.86
Days to 50% Silking	507.14**	6.53	22.36**	3.47**	0.83
AnthesisSilkingInterval	0.07	0.11	0.26**	0.07	0.11
Days to 50% Maturity	2280.25**	64.11	44.63	12.36**	4.65
Plant height	292354.69**	2739.38	3422.95**	571.36**	58.43
Ear height	778.35	1450.20	1272.23**	0.10	36.74
Cobs/plant	0.01	0.01	0.10**	0.00	0.04
Cob length	817.99**	12.46	23.83**	3.06**	0.85
Cob girth	326.42**	20.13	11.91**	1.56**	0.58
Kernel Rows/cob	894.78**	29.91	8.92**	2.01**	1.26
Kernels/row	4198.59**	8.75	111.33**	15.11**	3.75
100 kernel weight	464.67	292.42	116.62**	0.17	0.92
Grain yield/plant	23580.38**	1246.34	2435.54**	43.46**	28.49
Biological yield/plant	62938.20**	2534.40	6547.60**	1495.40**	332.20
Harvest index	1549.71	609.21	247.29**	61.23**	16.63
Chlorophyll (SPAD)	5741.69	84.95	87.31**	29.01**	0.76
LRWC	2334.00	50.07	389.00**	181.40**	0.00
Flag leaf area	82050.00	1.68	5417.00**	899.00**	0.00
Leaf area/plant	36289841.00	1534201.00	2607414.00**	188470.00**	21248.00
LAI	25.20	1.07	1.81**	0.13**	0.01
LAR	11474.16	19.64	357.53**	72.85**	42.00
SLW	11.85	2.41	3.16**	0.33**	0.10
SLA	7467.30	2111.00	2224.70**	316.60**	118.20
Starch	3.05	3927.03	93.44**	0.98	4.92
Protein	0.02	34.69	9.33**	0.02	0.05
Oil	0.36	2.18	5.28**	0.04	0.17

*LAI = Leaf area index; LAR=Leaf area ratio, LRWC = Leaf relative water content; SLA = Specific leaf area; SLW = Specific leaf area, ** = Significant at 1% probability level*

Table 2 General combining ability effects for physiological, quantitative and qualitative traits in maize (*Zea mays* L.)

Parents	Env.	Days to 50 % tasseling	Days to 50 % silking	Grain yield/ Plant	Days to 50 % maturity	100 seed weight	Chlorophyll SPAD	LRWC	Leaf area index	Leaf area ratio	Starch Content	Protein Content	Oil Content
	E_1	-0.91**	-0.88**	-10.37**	-1.43**	-1.27**	0.55**	4.41**	-0.14**	2.10	-0.48	-0.12	0.22**
Early yellow (P_1)	E_2	-1.38**	-1.43**	-8.47 **	-1.78**	-1.28**	0.54**	-3.73**	-0.13**	2.05**	-0.27	-0.10	0.22**
	E_3	-1.01**	-1.07**	-7.44 **	-2.12**	-1.48*	-1.48**	-5.06**	-0.18**	0.70	-0.49	-0.12	0.21**
	E_1	-0.69**	-0.74**	1.60	-0.98**	1.07**	0.77**	-1.30**	-0.08*	-1.12	-1.33**	0.23	0.10
POP- 445 (P_2)	E_2	-1.11**	-1.18**	1.46 **	-0.96*	1.00**	0.77**	-0.57**	0.01	0.39	-1.05	0.21	0.04
	E_3	-1.01**	-1.04**	0.44 **	-2.09**	1.06	-1.78**	0.17	0.05**	0.81*	-1.09	0.20	0.08
	E_1	-0.66**	-0.69**	-8.51**	0.68*	0.78**	0.08	0.98**	-0.22**	1.04	0.33	-0.13	-0.07
POP -31 Q2 (P_3)	E_2	-0.47**	-0.48**	-8.70 **	-1.53**	0.58**	0.08	0.21	-0.28**	-2.38**	0.17	-0.10	-0.01
	E_3	0.46**	0.49**	-7.62 **	-1.62**	0.75	-1.59**	-2.50**	-0.25**	-1.60**	0.32	-0.13	-0.04
	E_1	-0.16	-0.24	-6.22**	-0.68*	-0.80**	-0.47**	-1.22**	0.05	3.17	0.26	-0.25	0.18*
CML -359 (P_4)	E_2	-0.49**	-0.54**	-4.77 **	0.14	-0.84**	-0.47*	-4.16**	-0.06	-0.26	0.28	-0.27*	0.27**
	E_3	-0.23	-0.23	-4.17 **	0.49	-0.87	-1.46**	-3.41**	-0.03	1.09**	0.24	-0.23	0.25**
	E_1	-0.11	-0.05	7.22**	0.52	-0.15	-0.25	0.95**	0.03	-1.35	-0.96	0.02	-0.14
CM 129 (P_5)	E_2	0.01	0.07	6.25 **	0.64	-0.08	-0.25	-2.81**	-0.01	-1.47*	-0.85	0.02	-0.15*
	E_3	0.41*	0.46**	4.90 **	0.93	-0.16	2.24**	0.89**	0.13**	-0.63	-0.74	0.02	-0.11
	E_1	0.51**	0.53**	8.52**	-0.07	0.85**	0.43**	1.55**	0.21**	-2.36	-0.35	0.30*	0.03
LM 13 (P_6)	E_2	0.64**	0.68**	7.35 **	1.93**	0.76**	0.42*	2.92**	0.25**	-0.48	-0.24	0.22*	-0.03
	E_3	0.10	0.16	5.97 **	1.63**	0.85	1.15**	0.48**	0.26**	-0.30	0.12	0.26*	-0.07
	E_1	0.23	0.20	0.45	-0.09	-1.74**	-1.63**	0.77**	-0.05	-1.23	1.77**	0.06	-0.07
CM- 124 (P_7)	E_2	0.45**	0.41**	-0.61 *	0.69	-1.70**	-1.63**	-0.22	-0.02	0.37	1.36*	0.11	-0.18*
	E_3	-0.23	-0.26	-0.79 **	0.48	-1.67**	-0.24	2.85**	-0.04*	1.41**	1.31	0.10	-0.21**
	E_1	1.01**	1.12**	1.69	1.10**	-0.76**	-0.18	-1.41**	0.04	-2.20	0.79	-0.34**	-0.40**
DMR QPM-28 (P_8)	E_2	1.03**	1.13**	0.89 **	1.05**	-0.68**	-0.18	1.75**	0.10**	1.79**	0.51	-0.35**	-0.37**
	E_3	0.66**	0.60**	1.15 **	2.21**	-0.66	-0.79*	0.46**	0.01	0.26	0.46	-0.32*	-0.35**
	E_1	-0.22	-0.22	-0.37	0.46	-0.08	1.38**	-4.17**	-0.01	1.31	0.93	-0.26*	0.04
CML- 41 (P_9)	E_2	0.51**	0.54**	0.22	-0.14	0.03	1.38**	1.69**	-0.07*	1.09	0.75	-0.18	0.04
	E_3	-0.04	-0.01	2.43 **	0.31	0.02	2.78**	1.91**	-0.08**	-1.29**	0.70	-0.22	0.09
	E_1	1.01**	0.98**	5.99**	0.49	2.09**	-0.67**	-0.55**	0.17**	0.64	0.95*	0.48**	0.14
HKI-193-2 (P_{10})	E_2	0.81**	0.79**	6.40 **	-0.03	2.22**	-0.67**	4.92**	0.19**	-1.11	0.65*	0.45**	0.16*
	E_3	0.91**	0.91**	5.14 **	-0.21	2.15**	1.17**	4.21**	0.12**	-0.46	0.70*	0.44**	0.16*

*LRWC-Leaf relative water content,*Significant at 5% level; **Significant at 1%level*

Table 3: Single cross maize hybrids identified on the basis of *per se* performance and specific combining ability for grain yield, physiological and quantitative traits in E_1, E_2 and E_3 environments

Hybrids	Env.	Mean	Economic heterosis (%)	*Specific combining ability (sca)*											
		Grain yield/ plant (g)	(hc)	Grain yield/plant (g)	Days to 50 % tasseling	Days to 50 % silking	Days to 50% maturity	100 seed weight	Chlorophyll SPAD	LRWC	LAI	LAR	Starch content	Protein content	Oil content
CM- 124 x	E_1	132.42	36.73*	41.23*	0.33	0.30	-2.52*	4.58*	3.13*	6.05*	0.68**	-3.79	-3.14	0.74*	-0.98*
LM-13	E_2	112.19	71.00 *	34.48 *	-0.94	-0.92	-2.56*	4.95*	3.13*	8.36*	0.88**	2.52	-2.51	0.80*	-0.93*
	E_3	81.18	61.12 *	17.23 *	-1.21*	-1.24*	-3.52*	4.82	1.61*	6.14*	0.46**	4.60**	-2.66	0.67*	-0.80*
HKI-193-2	E_1	133.06	37.39*	37.63*	0.17	0.11	-1.49*	1.81*	-6.02*	7.73*	0.38*	11.17*	1.25*	-1.68*	-0.38
x CM 129	E_2	114.11	73.94 *	30.49 *	0.34	0.30	-1.93*	1.89*	-6.02*	5.05*	0.60*	2.77*	0.73*	-1.44*	-0.31
	E_3	81.47	61.70 *	12.67 *	2.01**	1.95**	-0.49*	1.68*	-2.28*	8.82*	0.90*	-0.35	0.70*	-1.59*	-0.13
DMR-	E_1	123.73	27.76*	39.37*	-1.50**	-1.61**	3.32*	6.03*	7.00*	5.07*	0.44**	-9.09	-3.27	-0.84	-0.57*
QPM-28 x	E_2	102.90	56.84 *	31.66 *	-1.66**	-1.70**	-1.90*	6.57*	7.00*	7.30*	0.46**	5.67**	-2.35	-0.84	-0.58*
CM- 124	E_3	81.62	62.00 *	22.49 *	-0.43	-0.02	-0.40*	6.24*	1.15	4.40*	0.42**	3.84**	-2.17	-0.86	-0.52*
HKI-193-2	E_1	115.07	18.81*	25.26*	-1.58*	-1.86**	0.82	8.22*	3.08*	1.94*	-0.24*	13.88*	-0.09	-0.78	0.55*
x POP	E_2	103.33	57.50 *	24.51 *	-0.88	-1.45**	-0.83*	8.47*	3.08*	-15.52*	-0.17	8.51*	0.86	-0.79	0.50*
445	E_3	80.78	60.32 *	16.43 *	0.76	0.45	-0.41*	8.40*	2.24	-8.43*	0.18*	5.36*	-0.20	-0.83	0.68*
CML 41 x	E_1	109.47	13.03*	26.01*	0.97*	1.00*	-1.16*	4.75*	-2.93*	3.59*	0.11	-10.37	-1.80	0.30	0.82*
POP 445	E_2	100.74	53.55 *	28.10 *	-0.91*	-0.86*	-1.05*	5.01*	-2.94*	9.29*	0.17	9.48**	-1.91	0.34	0.94*
	E_3	80.63	60.03 *	18.99 *	-0.63	-0.64	2.08	4.66*	-2.67*	5.64*	0.10	5.22**	-1.55	0.29	0.91*

*LRWC-Leaf relative water content, LAI-Leaf area index, LAR-Leaf area ratio*Significant at 5% level*

Chlorophyll content (SPAD)- The *gca* analysis revealed that the parent CML- 41 (P_9) was a good general combiner for the trait in all three environments.The *gca* effect for chlorophyll content varied from 0.43** (LM 13) to 1.38** (CML- 41) in $E_{1,}$ from 0.42* (LM 13) to 1.38** (CML- 41) in E_2, while it ranged from 1.15** (LM 13) to 2.78** (CML- 41) in $E_{3.}$ The results were supported by the findings of Hemalatha *et al.* (2013).

Leaf relative water content (LRWC)-From the combining ability analysis, results of the *gca* reveal that parent Early yellow (P_1) in $E_{1,}$ and HKI-193-2 (P_{10}) in E_2 and E_3 were good sources of favourable genes for increasing leaf relative water content, because they were found to be good general combiners.The *gca* effect for leaf relative water content varied from 0.77** (CM-124) to 4.41** (Early yellow) in $E_{1,}$ from1.69** (CML- 41) to 4.92** (HKI-193-2) in E_2, and from 0.46** (DMR QPM-28) to 4.21** (HKI-193-2) in $E_{3.}$

Leaf area index-Study on general combining ability analysis revealed that the parent LM 13 (P_6) was a good source for favourable alleles for leaf area index since they had significant positive *gca* effects. The *gca* effect for leaf area index varied from 0.03 (CM 129) to 0.21** (LM 13) in $E_{1,}$ from 0.01(POP- 445) to 0.25** (LM 13) in E_2, and from 0.05** (POP- 445) to 0.26** (LM 13) in $E_{3.}$ The results were supported by the findings of Hemalatha *et al.* (2013).

Leaf area ratio- The results revealed that the parent Early yellow (P_1) and line CM- 124 (P_7) was a good source for favourable alleles for leaf area ratio since they had significant positive *gca* effects in E_2 and E_3 respectively. The *gca* effect for leaf area ratio varied from 0.64 (HKI-193-2) to 3.17 (CML -359) in $E_{1,}$ from 0.37(CM- 124) to 2.05** (Early yellow) in E_2, and from 0.81* (POP-445) to 1.41** (CM- 124) in $E_{3.}$

Quality traits-General combining ability analysis reveal that the parents CM- 124 (P_7) had significant positive *gca* effects in environment E_1 and $E_{2.}$The *gca* effect for starch content varied from 0.26 (CML -359) to1.77** (CM- 124) in $E_{1,}$ from 0.17 (POP -31 Q2) to 1.36* (CM- 124) in E_2, and from 0.32 (POP-31 Q2) to 1.31 (CM-124) in $E_{3.}$ Parents CM- 124 (P_7) (1.77**) and (1.36*) exhibited highest significant positive *gca* effects for starch content in environments E_1 and E_2 respectively. The parents HKI-193-2 (P_{10}) and LM-13 (P_6) exhibited significant positive *gca* effects in all environments suggesting them as good sources of favorable genes and good general combiners for increasing protein content. The *gca* effect for protein content varied from 0.02 (CM 129) to 0.48** (HKI-193-2) in $E_{1,}$ from 0.02(CM 129) to 0.45** (HKI-193-2) in E_2, and from 0.10 (CM- 124)to 0.44** (HKI-193-2) in $E_{3.}$ The results were supported by the findings of Sukumar (2020).

Oil content-Study revealed that parent CML - 359 (P_4) and HKI-193-2 (P_{10}) were good general combiner for the trait as they exhibited highest significant positive *GCA* effects for oil content in all environments. The *GCA* effect for oil content varied from 0.04 (CML- 41) to 0.22** (Early yellow) in $E_{1,}$ from0.04 (POP- 445) to 0.27** (CML -359) in E_2, and from 0.08 (POP- 445) to 0.25** (CML -359) in $E_{3.}$The results were supported by the findings of Khan *et al.* (2014).

Specific combining ability effect in single cross maize hybrids across environments

Yield and yield attributes-T he crosses CM-124 x LM-13, HKI-193-2 x CM 129, DMR-QPM-28 x CM- 124, HKI-193-2 x POP 445 and CML 41 x POP 445 exhibited significantly positive *sca* effects for grain yield per plant in all the environments E_1, E_2 and $E_{3.}$ For days to 50 % tasselling the crosses CM- 124 x LM-13 in E_3, DMR-QPM-28 x CM- 124 in E_1 and E_2, HKI-193-2 x POP 445 in E_1 andCML 41 x POP 445in E_2 exhibited significantly negative *sca* effects. For days to 50 % silking the crosses, CM- 124 x LM-13 in E_3, DMR-QPM-28 x CM- 124 in E_1 and E_2, HKI-193-2 x POP 445 in E_1 and E_2 and CML 41 x POP 445 in E_2 exhibited significantly negative *sca* effects. For days to 50 % maturity the crosses CM- 124 x LM-13 in $E_{1,}$ E_2 and $E_{3,}$ HKI-193-2 x CM 129 in $E_{1,}$ E_2 and $E_{3,}$ DMR-QPM-28 x CM- 124 in E_1, E_2 and E_3, HKI-193-2 x POP 445 in E_2 and $E_{3,}$CML 41 x POP 445 in E_1, E_2 exhibited significantly negative *sca* effects. For one hundred seed weight, the crosses CM- 124 x LM-13, HKI-193-2 x CM 129, DMR-QPM-28 x CM- 124, HKI-193-2 x POP 445 and CML 41 x POP 445 exhibited significantly positive *sca* effects.The results were supported by the findings of ShimelisTesfaye andBerhanu Sime (2021).The crosses CM- 124 x LM-13 in E_1, E_2 and E_3, DMR-QPM-28 x CM- 124 in $E_1$and E_2, HKI-193-2 x POP 445 $E_1$and E_2 exhibited significantly positive *sca* effects for chlorophyll content.The crosses CM- 124 x LM-13, HKI-193-2 x CM 129, DMR-QPM-28 x CM- 124, CML 41 x POP 445 in all the environments E_1, E_2 and E_3, while HKI-193-2 x POP 445 in E_1 exhibited significantly positive *sca* effects for Leaf relative water content (LRWC).The crossesCM- 124 x LM-13, HKI-193-2 x CM 129, DMR-QPM-28 x CM- 124 in all the environments E_1, E_2 and E_3, whileHKI-193-2 x POP 445 in E_3, showed significantly positive *sca* effects for Leaf area index (LAI).The crosses CM- 124 x LM-13 in E_1, HKI-193-2 x CM 129 in E_1 and E_2, DMR-QPM-28 x CM- 124 in E_2 and E_3, HKI-193-2 x POP 445 in E_1, E_2 and E_3, CML 41 x POP 445 in E_2 and E_3 showed significantly positive *sca* effects for leaf area ratio (LAR). Similarly the cross HKI-193-2 x CM 129 showed significantly positive *sca* effects in all three environments E_1, E_2 and E_3 for starch content.The cross CM- 124 x LM-13 showed significantly positive *sca* effects in all three environments E_1, E_2 and E_3 for protein content.The crosses HKI-193-2 x POP 445 and CML 41 x POP 445 showed significantly positive *sca* effects in all three environments E_1, E_2 and E_3 for oil content.

From the findings it may be conclued that the parents HKI-193-2 (P_{10})LM 13(P_6) and line CM 129 (P_5) were found to be good general combiners for grain yield per plant as they exhibited significant positive *gca* effects in environments E_1, E_2 and E_3. The parent HKI-193-2 (P_{10})showed significant positive *gca* effects for one hundred seed weight in all environments and the line LM 13 (P_6) and POP- 445 (P_2) in environments E_1 and E_2. The parent CM- 124(P_7) for starch content in environments E_1 and E_2, and the parents CML -359 (P_4) and HKI-193-2 (P_{10})were good general combiner for oil content in all the three environments. The parent HKI-193-2 (P_{10}) in E_2 and E_3 were good sources of favorable genes for increasing leaf relative water content. The parents LM 13 (P_6) and HKI-193-2 (P_{10}) were found to be good general combiners for Leaf area Index in all the three environments. The parent CM- 124 was found to be good general combiners for Leaf area Ratio in the environment E_3. The hybrid CM- 124 x LM-13 showed good specific combining ability effects for grain yield, days to 50 % tasseling, days to 50 % silking, days to 50% maturity, 100 seed weight, chlorophyll content SPAD, Leaf relative water content, Leaf area index, leaf area ratio and protein content.The hybrid HKI-193-2 x CM 129showed good specific combining ability effects for grain yield, days to 50% maturityone hundred seed weight, Leaf area index, leaf area ratio andstarch content.

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