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Combining Ability and Heterosis for Grain Yield and Quantitative Traits in Maize (*Zea mays* L.)

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Abstract—*A field experiment was conducted to evaluate the combining ability and heterosis for grain yield and quantitative traits in maize by using Line x Tester design during kharif season of 2015 and Rabi 2016. The analysis of variance showed significant differences in genotypes for all the characters under investigation. Further, the partitioning of genotypes showed that parents differed significantly for all the traits. It suggests presence of sufficient diversity in the experimental material. The estimates of general combining ability effects indicated that the parents CML 465 (3.92), CML 470 (2.56) and CML 287 (1.59) were observed to have a good general combiners kernel yield per plant. The estimates of SCA effect revealed that the cross combination CML 197 X CML 486 (7.10), CML 431 X CML 465 (6.25), CML 431 X CML 453 (5.73) and CML 287 X CML 496 (3.91) were observed most promising hybrids for grain yield per plant and some of its related traits viz., plant height, number of kernels per row and 1000 kernel weight. The crosses, CML 431 X CML 465 (65.99%, 29.28%), CML 197 X CML 470 (50.48%, 34.23%), CML 287 X CML 496 (53.57%, 10.44%), CML 431 X CML 470 (48.51%, 15.66%), CML 431 X CML 453 (48.09%, 15.34%), CML 197 X CML 496 (40.09%, 26.38%) and CML 197 X CML 465 (41.24%, 13.30%) exhibited significant and positive heterosis for the trait kernel yield per plant over standard heterosis and better parent heterosis respectively.*

Keywords*: Maize, kernel yield, heterosis, combining ability, variability.*

1. INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop of the world. It occupies third place after wheat and rice in world production. Globally occupying 161 million ha area with production of more than 800 million tones and productivity of 5.1 tonnes/ha, which is grown in more than 167 countries in diverse seasons for diverse use in different agro-ecological conditions due to its high yield potential and evergreen crop for major maize growing countries like USA, China, Brazil, European union, Ukraine, Argentina, India, Mexico etc. (USDA 2013-2014). Maize seed contains average 66.2% carbohydrates, 11.1% protein, 14.9 % moisture, 3.6% fat, 2.7% fiber and 1.5% minerals (Jebaraj *et al.,* 2010). Among cereal crops, it is used worldwide for about 3500 products of different uses as feed (61%), food (17%) and basic raw industrial materials (22%). It occupies the unique place as "Queen of cereals" (Anonymous 2011). Modern maize breeding was based on the inbred-hybrid concept described by Shull (1952).

Evaluation of breeding materials for general combining ability and specific combining ability as well as to study the extent of heterosis for yield and yield contributing characters are prerequisites for any breeding programme aimed in development of hybrids. Combining ability also provide information on the nature and magnitude of gene effects involved in the expression of quantitative traits. Such information is of practical value in formulating as well as executing efficient breeding programme for obtaining maximum gain with minimum resource and time (Hallauer and Miranda, 1988).

Heterosis breeding is the most successful approach, among the different option available. By relating level of heterosis with combining ability, the concept of heterotic groups was established.

Different mating designs have been used by different breeders as an aid, in the choice of desirable parents and to understand their genetic nature for the development of hybrids. Line x Tester analysis suggested by Kempthorne (1957).

2. MATERIAL AND METHOD

The experimental material consisted of 21 F_1 hybrids, 7 lines (male), 3 testers (female). CML 453, CML 465, CML 470, CML 480, CML 481, CML 486 and CML 496 used as lines CML 197, CML 287 and CML 431 as testers and CML 197 as standard check. The crossing programme includes bagging and pollination. Randomized Complete Block Design was followed to conduct experiment with three replication. Each plot consisted of two rows of 5 m length with spacing of 60 cm between rows and 20 cm between plant to plant within a row.

The following quantitative and qualitative characters were recorded plot wise and replication wise to carry out statistical analysis.

2.1 Plant height (cm): The plant height of each of randomly selected five plants measured in cm from ground level to base of flag leaf at dry husk stage. The mean height per plant was computed for each test entry.

2.2 Ear height (cm): The ear height of each of randomly selected five plants measured in cm from base of plant to node of uppermost ear. The mean ear height per plant was worked out for each test entry.

2.3 Days to pollen shedding: The number of days taking or dehiscence of anther and coming out of mature pollen grain was observed for the grow entry for each genotype.

2.4 Days to silking: The number of days is needed to emerge silk from the date germination in all the plants within a plot of genotype was observed.

2.1.5 Ear Length (cm): Length of ears of randomly selected plants measured in centimeter from base of ear to tip of ear and mean length of ear was computed to get for each genotype.

2.1.6 Ear diameter (cm): Ear diameter of each of the five randomly selected ears of a plot was measured with the help of slide caliper. The measurements were taken at the middle of ear after removing the husk cover.

2.7 Number of kernel rows per ear: The number of kernel rows per ear of each of five randomly selected plants counted after dehusking the ears. The mean value of kernel rows per ear calculated to obtain value for each genotype.

2.8 Number of kernels per row: The number of kernels per row of each ear of five randomly selected plants was counted for kernels rows per dehusked ear. The mean value of kernels per row worked out to get value for each test entry.

2.9 Number of kernels per ear: The number of kernels per ear of five randomly selected ears was counted. The mean value of kernels per ear worked out to get value for each test entry.

2.10 1000 kernel weight (g): One thousand kernels from composite samples of ears of five randomly selected plants from each of entry weighed in gram.

2.11 Kernel yield per plant (g)

The ears of the randomly selected and tagged five plants were shelled and kernels from ear were weighed and divided by the total number of plants and mean kernels yield per plant was worked out for each plot and recorded separately.

Statistical Methodology

The mean data generated for the various characters were used for statistical analysis under the following sub heads:

Analysis of variance

Estimation of heterosis

Combining ability analysis

3. RESULTS

The experiment consisted of 31 genotypes (7 lines, 3 testers and 21 single cross hybrids) developed as per Line x Tester Mating Design which was conducted at Agricultural Research Farm, The School of Agriculture at Lovely Professional University at Phagwara (Punjab) during *Kharif* 2015 and *Rabi* 2016. The results obtained after statistical analysis are presented here under the following sub-heads:

3.1 Analysis of variance for line x tester mating design

3.2 Estimation of components of genetic variance

3.3 General combining ability effects (GCA)

3.4 Specific combining ability effects (SCA)

3.5 Proportional contribution of lines, testers and their interaction to total variance

3.6 Estimation of general means, heritability, genetic advance and genetic advance as % of mean

3.7 Extent of heterosis

3.1 Analysis of variance for line x tester mating design

The data subjected to analysis of variance for different characters are given in Table 3.1. The results revealed that almost all the characters exhibited highly significant genotypic differences. It indicated that experimental genotypes had sufficient genetic diversity for the different traits.

Table 3.1: Analysis of variance for line x tester analysis of yield, its component and traits of maize during *rabi* 2016.

Sources of Variations	df	Mean Sum of Squares										
		Plant height in cm	Ear height in cm	Days to pollen shedding	Days to silking	Ear length (cm)	Ear diameter (cm)	Number of kernel rows/ear	Number of kernels /row	Number of kernels/ear	1000 kernel wt. (g)	kernel yield/plant(g)
Replicates	2	0.69	4.02	0.81	1.17	2.83	0.04	0.04	1.59	10.54	12.36	24.11
Treatments	30	638.95**	161.16**	16.50**	26.74**	2.28**	0.05**	3.74**	31.42**	6075.49**	416.97**	142.45**

Parents	9	672.84**	207.09**	28.98**	37.27**	2.93*	0.07**	4.80**	34.67**	6155.41**	682.47**	148.60**
Crosses	20	527.63**	131.88**	11.69**	23.27**	1.80	0.04**	3.25**	29.65**	5579.12**	259.21**	68.92**
Parents vs. Crosses	1	2560.33**	333.33**	0.55	1.39	6.03	0.06	3.95**	37.60**	15283.90*	1182.78**	1557.79**
Lines (Male)	6	706.03**	334.49**	24.28**	37.08**	0.98	0.02	9.88**	3.20	3316.17**	154.16	67.30
Testers (Female)	2	2343.40**	230.46**	38.92**	99.61**	12.49**	0.26**	0.20	260.20*	42425.19*	105.26	68.82
Lines x Testers	12	135.81**	14.14**	0.86	3.63*	0.42	0.02	0.44*	4.45**	569.57**	337.39**	69.76**
Error	92	7.53	7.73	0.58	1.47	1.08	0.02	0.22	0.60	224.50	51.68	9.32

3.2 Estimation of components of genetic variance

The estimation of components of genetic variance i.e., variance due to lines (male σ^2 gm), testers (female σ^2 gf), GCA (σ^2 GCA), SCA (σ^2 SCA), additive (σ^2A), dominance (σ^2D) and average degree of dominance $\sqrt{(\sigma^2 D / \sigma^2 A)}$ were estimated for all the traits (Table 3.2).

Table 3.2: Estimates of genetic components of variance (σ^2A and σ^2D) and degree of dominance for yield, its component and traits of maize during *rabi* 2016

Components of variance	Plant height in cm	Ear height in cm	Days to pollen shedding	Days to silking	Ear length (cm)	Ear diameter (cm)	Number of kernel rows/ear	Number of kernels /row	Number of kernels/ear	1000 kernel wt. (g)	kernel yield/plant(g)
σ^2Male	77.61**	36.30**	2.63**	3.95**	-0.01	0.0008	1.07**	0.28	343.51**	11.38	6.44
σ^2Female	111.23**	10.60**	1.82**	4.67**	0.5431**	0.0116**	-0.0007	12.36**	2009.55**	2.55	2.83
σ^2GCA	101.14**	18.31**	2.06**	4.45**	0.37**	0.0084**	0.32**	8.74**	1509.75**	5.20	3.91
σ^2SCA	42.75**	2.13	0.09	0.72*	-0.22	-0.0003	0.07*	1.28**	115.02*	95.23	20.14**
σ^2A	404.58	73.26	8.27	17.83	1.50	0.033	1.28	34.96	6038.98	20.80	15.66
σ^2D	171.03	8.55	0.37	2.88	-0.88	-0.0014	0.30	5.12	460.10	380.94	80.58
Degree of Dominance $\sqrt{(\sigma^2 D / \sigma^2 A)}$	0.65	0.34	0.21	0.40	0.76	0.20	0.48	0.38	0.27	4.27	2.26

Table 3.3: Estimates of general combining ability effects for yield, its component and traits in maize during *rabi* 2016.

	Plant height in cm	Ear height in cm	Days to pollen shedding	Days to silking	Ear length (cm	Ear diameter (cm)	Number of kernel rows/ear	Number of kernels /row	Number of kernels/ear	1000 kernel wt. (g)	kernel yield/plant(g)
					Lines						
CML 453	5.15**	3.40**	0.86**	2.02**	-0.06	-0.07	-0.51**	0.10	19.59**	3.39	-3.82**
CML 465	6.71**	-1.96*	2.30**	2.46**	0.04	0.09	-0.51**	-0.46	-2.41	-6.42*	3.92**
CML 470	-12.31**	-5.90**	-1.70**	-2.43**	0.11	-0.06	-0.29	-0.57*	-6.75	-0.03	2.56*
CML 480	-12.83**	-5.81**	-0.25	-0.10	0.20	0.04	0.38*	0.87**	26.92**	3.71	-1.45
CML 481	2.47*	1.87*	-1.92**	-1.10**	-0.37	-0.03	1.27**	-0.35	-8.86	40.48	-1.95
CML 486	2.36*	-2.89**	0.92**	-2.32**	0.52	0.00	1.27**	-0.35	2.59	-3.80	1.40

CML496	8.45**	11.28**	1.63**	1.46**	-0.44	0.01	-1.62**	0.76**	-31.08**	-1.34	-0.68
Std.Error	±0.91	±0.92	±0.25	±0.40	±0.34	±0.04	±0.15	±0.25	±4.99	±2.39	±1.01
Testers											
CML 197	3.19**	0.29	-1.17**	-0.86**	-0.63**	-0.01	-0.03	-2.89**	-41.10**	1.80	-1.97**
CML 287	8.60**	3.16**	1.49**	2.48**	0.86**	0.12**	0.11	3.92**	48.00**	-2.51	1.59*
CML 431	-11.79**	-3.45**	-0.32	-1.62**	-0.23	-0.11**	-0.08	-1.03**	-6.90*	0.70	0.39
Std.Error	±0.59	±0.60	±0.16	±0.26	±0.22	±0.03	±0.10	±0.16	±3.26	±1.56	±0.66

Table 3.4: Estimates of specific combining ability effects for yield, its component and traits in maize during *rabi* 2015-16.

	Plant height in cm	Ear height in cm	Days to pollen shedding	Days to silking	Ear length (cm)	Ear diameter (cm)	Number of kernel rows/ear	Number of kernels /row	Number of kernels/ear	1000 kernel wt. (g)	kernel yield/plant(g)
CML 197 X CML 453	-6.30**	0.44	0.62	0.08	-0.12	-0.08	0.03	-0.33	-7.02	-8.75*	-6.14**
CML 197 X CML 465	-7.75**	2.11	0.17	0.30	0.26	0.03	0.37	0.56	-6.68	0.03	-2.82
CML 197 X CML 470	2.95	1.01	-0.49	-0.81	-0.08	-0.02	-0.52	-1.33**	-14.68	7.13	2.80
CML 197 X CML 480	4.32**	0.77	-0.27	-0.48	-0.20	-0.02	-0.19	0.22	-1.68	-6.42	-0.80
CML 197 X CML 481	1.08	-1.69	0.06	-1.14	0.00	0.14	0.25	-0.56	13.43	-7.42	-1.39
CML 197 X CML 486	2.95	-0.66	-0.60	1.41	0.12	0.02	0.25	1.11*	16.98	9.77*	7.10**
CML 197 X CML 496	2.74	-1.98	0.51	0.63	0.02	-0.06	-0.19	0.33	-0.35	5.65	1.24
CML 287 X CML 453	9.26**	1.5	-0.05	-0.59	0.52	0.13	0.22	0.19	7.56	-3.73	0.41
CML 287 X CML 465	11.01**	-0.41	-0.49	-1.03	-0.17	0.01	-0.44	-0.59	15.22	-7.05	-3.43
CML 287 X CML 470	-1.11	-1.90	0.51	1.19	-0.03	0.02	0.33	2.52**	-3.11	-3.02	-2.33
CML 287 X CML 480	-1.49	-2.56	0.40	0.86	0.17	0.02	0.33	-0.59	-6.44	18.01**	1.88
CML 287 X CML 481	-4.26*	1.14	-0.60	1.52	0.33	-0.11	0.11	0.97*	-4.33	-2.87	2.78
CML 287 X CML 486	-8.27**	2.69	0.40	-1.59	-0.18	-0.07	-0.56*	-1.70**	1.89	-4.27	-3.23
CML 287 X CML 496	-5.14**	-0.52	-0.16	-0.37	-0.64	0.02	0.00	-0.81	-10.78	2.94	3.91*
CML 431 X CML 453	-2.96	-1.99	-0.57	0.51	-0.40	-0.05	-0.25	0.14	-0.54	12.48**	5.73**
CML 431 X CML 465	-3.26*	-1.71	0.32	0.73	-0.09	-0.04	0.08	0.03	-8.54	7.03	6.25**
CML 431 X CML 470	-1.84	0.89	-0.02	-0.38	0.11	0.01	0.19	-1.19*	17.79*	-4.11	-0.47
CML 431 X CML 480	-2.84	1.79	-0.13	-0.38	0.03	0.01	-0.14	0.37	8.13	-11.60**	-1.08
CML 431 X CML 481	3.19	0.54	0.54	-0.38	-0.33	-0.02	-0.37	-0.41	-9.10	10.29*	-1.39
CML 431 X CML 486	5.32**	-2.03	0.21	0.17	0.06	0.05	0.30	0.59	-18.87*	-5.49	-3.87*
CML 431 X CML 496	2.39	2.51	-0.35	-0.27	0.62	0.04	0.19	0.48	11.13	-8.59*	-5.16**

Table 3.5: Estimates of standard heterosis and better parent heterosis for yield, its component and traits of maize during *rabi* 2016.

Traits / Crosses	Plant height in cm		Ear height in cm		Days to pollen shedding		Days to silking		Ear length (cm		Ear diameter (cm)	
	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH
CML 197 X CML 453	11.90**	3.23	8.06	-0.52	3.36**	-2.12**	4.66**	-1.68	5.10	5.10	-0.83	-0.83
CML 197 X CML 465	11.99**	3.30	0.77	0.77	4.48**	-3.45**	5.38**	-1.67	9.90	0.92	5.83*	1.60
CML 197 X CML 470	4.76*	29.30**	-9.23*	-9.23*	-0.75	-0.75	-1.08	-1.08	7.18	2.37	0.83	0.00
CML 197 X CML 480	5.49**	28.45**	-9.54*	-9.54*	1.12	-1.45*	1.79	-1.05	6.98	-1.15	3.33	-0.80
CML 197 X CML 481	15.99**	13.44**	0.83	0.83	-0.37	-0.37	0.00	-0.71	3.15	3.15	5.58	5.58
CML 197 X CML 486	17.53**	13.18**	-6.59	-6.59	0.00	-0.37	1.43	1.43	13.36	-1.89	3.33	0.00
CML 197 X CML 496	22.65**	11.77**	18.89**	1.35	4.10**	-1.76*	4.66**	-2.34*	2.68	-4.08	1.67	-0.81
CML 287 X CML 453	30.17**	20.08**	15.95**	6.75	5.60**	-0.35	7.53**	-0.33	26.51**	-3.08	7.50*	-1.53
CML 287 X CML 465	33.05**	22.72**	1.46	-6.03	6.72**	-1.38*	7.53**	-0.33	20.57*	-7.63	8.33**	-0.76
CML 287 X CML 470	5.93**	30.75**	-9.30*	-16.00**	3.36**	-2.46**	4.66**	-2.99**	22.65*	-6.04	5.00	-3.82
CML 287 X CML 480	5.15*	28.04**	-10.43*	-17.05**	4.85**	-1.06	6.81**	-1.00	25.64**	-3.75	7.50*	-1.53
CML 287 X CML 481	16.05**	13.50**	12.13*	3.84	1.87*	-3.87**	6.45**	-1.33	21.51*	-6.92	2.50	-6.11*
CML 287 X CML 486	12.47**	8.31**	5.74	-2.07	4.10**	-1.76*	1.79	-5.65**	25.37**	-3.96	4.17	-4.58
CML 287 X CML 496	20.51**	9.82**	27.48**	8.67*	6.34**	0.35	7.17**	-0.66	11.07	-14.91*	6.67	-2.29
CML 431 X CML 453	1.76	-6.12**	-4.16	-11.77**	2.99**	-2.47**	4.30**	-2.02	6.21	-2.62	-2.50	-0.85
CML 431 X CML 465	2.86	-5.12**	-14.22**	-3.89	5.60**	-2.41**	5.02**	-2.01	10.40	1.23	1.67	-2.40
CML 431 X CML 470	-12.46**	8.04**	-16.88**	0.43	0.75	-1.82*	-1.43	-2.14	13.09	3.69	-0.83	-1.65
CML 431 X CML 480	-13.79**	4.98*	-14.91**	2.82	2.24**	-0.36	1.08	-1.74	13.22	3.82	1.67	-2.40
CML 431 X CML 481	4.78*	2.48	-2.16	6.39	1.12	-1.45*	0.00	-0.71	3.89	-4.74	-0.83	0.85
CML 431 X CML 486	6.55**	2.61	-16.71**	0.64	1.87*	-0.73	-0.72	-1.42	16.78	1.07	1.67	-1.61
CML 431 X CML 496	9.30**	-0.39	20.38**	2.62	4.10**	-1.76*	2.87*	-4.01**	12.75	3.38	1.67	-0.81

Table 3.6: Estimates of standard heterosis and better parent heterosis for yield, its component and traits of maize during *rabi* 2016.

Traits / Crosses	Number of kernel rows/ear		Number of kernels /row		Number of kernels/ear		1000 kernel wt. (g)		kernel yield/plant(g)	
	SH	BPH	SH	BPH	SH	BPH	SH	BPH	SH	BPH
CML 197 X CML 453	2.78	2.78	17.31**	-4.69	26.62**	2.59	3.66	1.20	17.28**	4.39
CML 197 X CML 465	5.56	5.56	19.23**	-4.62	18.99**	-4.22	3.22	-1.69	41.24**	13.30**
CML 197 X CML 470	0.00	0.00	7.69*	-3.45	12.93*	2.53	8.87**	-2.55	50.48**	34.23**
CML 197 X CML 480	8.33*	-7.14*	25.00**	-5.80*	35.84**	-7.98	4.77	4.77	34.01**	-1.54
CML 197 X CML 481	19.44**	2.38	13.46**	-3.28	25.70**	-5.42	4.67	4.67	31.65**	2.32
CML 197 X CML 486	19.44**	2.38	23.08**	-3.03	33.06**	-5.13	8.40**	-0.59	57.29**	5.20

CML 197 X CML 496	-8.33*	-8.33*	25.00**	-4.41	8.02	-1.20	7.70**	7.70**	40.09**	26.38**
CML 287 X CML 453	5.56	5.56	59.62**	-8.79**	80.52**	1.75	3.95	-3.01	39.18**	0.09
CML 287 X CML 465	0.00	0.00	51.92**	-13.19**	73.49**	-2.21	-1.55	-8.14**	47.64**	6.17
CML 287 X CML 470	8.33*	8.33*	69.23**	-3.30	62.36**	-8.49*	2.82	-7.97**	47.08**	5.77
CML 287 X CML 480	13.89**	-2.38	59.62**	-8.79**	77.25**	-0.09	13.19**	5.61*	47.51**	6.07
CML 287 X CML 481	19.44**	2.38	61.54**	-7.69**	60.72**	-9.41**	4.76	-2.25	48.37**	6.69
CML 287 X CML 486	13.89**	-2.38	46.15**	-16.48**	69.39**	-4.52	0.71	-7.63**	42.61**	-4.61
CML 287 X CML 496	-5.56	-5.56	57.69**	-9.89**	46.64**	-17.34**	4.76	-2.26	53.57**	10.44*
CML 431 X CML 453	0.00	0.00	30.77**	-1.45	49.59**	12.15*	12.08**	9.43**	48.09**	15.34**
CML 431 X CML 465	2.78	2.78	26.92**	-4.35	34.86**	1.10	5.69*	0.66	65.99**	29.28**
CML 431 X CML 470	5.56	5.56	19.23**	-10.14**	45.66**	9.20*	3.70	-7.18**	48.51**	15.66**
CML 431 X CML 480	8.33*	-7.14*	36.54**	2.90	57.45**	6.65	2.13	2.90	38.49**	1.76
CML 431 X CML 481	13.89**	-2.38	25.00**	-5.80*	31.42**	-1.47	11.62**	12.45**	36.74**	6.28
CML 431 X CML 486	19.44**	2.38	30.77**	-1.45	32.24**	-5.72	1.54	-6.87**	38.63**	-7.28
CML 431 X CML 496	-5.56	-5.56	36.54**	2.90	30.44**	-2.21	1.28	2.04	31.34**	2.29

4. DISCUSSION

Genetic Variability: Analysis of variance revealed highly significant differences due to genotypes for all the 11 characters. Variances due to parents (females, males) were also highly significant for the plant height, ear height, days to pollen shedding, days to silking and number of kernels per ear. Crosses and parents vs crosses showed highly significant differences for all the traits except days to pollen shedding, days to silking, ear length and ear diameter in which parents vs crosses were found non-significant revealing the considerable amount of genetic variability present in the base material as well as material generated subsequently in present investigation.

Heterosis: The standard heterosis for kernel yield per plant ranged from 17.28 (CML 197 X CML 453) to 65.99 (CML 431 X CML 465). All the crosses showed positively significant standard heterosis.

Combining Ability: The estimates of GCA effects indicated that the parents CML 465 (3.92) and CML 470 (2.56) were observed to be good general combiners kernel yield per plant. The estimates of SCA effects for kernel yield per plant ranged from -6.14 (CML 197 X CML 453) to 7.10 (CML 197 X CML 486). Out of 21 crosses, 7 crosses showed significant SCA effect.

Heritability and Genetic Advance: Heritability is the ratio of genotypic variance to phenotypic variance (broad sense) or ratio of additive variance to the phenotypic variance (narrow sense). Estimates of heritability varied different traits. The number of kernels per ear (94.08%) revealed highest narrow sense heritability. The economic important trait kernel yield per plant showed 25.19% heritability.

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