Triallel analysis for grain yield and its components over pooled environments in maize (*Zea mays* L.)

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Abstract

Seven parents were utilized in crossing programme to produce 21 single crosses and 105 three-way crosses to study gene actions for grain yield and yield contributing characters. Triallel analysis was conducted for important yield components *i.e.*,ear length, ear diameter, number of kernel rows ear^{-1}, number of kernels row^{-1}, 100-grain weight, shelling percentage and grain yield. Significance of 1-line general line effects of both first and second kind, 2- line specific effects of first kind and second kind as well as 3-line specific effects for all the yield and yield contributing traits except number of kernels row^{-1} in case of 3-line specific effects suggested the major role of all three types of epistatic components *viz.*, additive × additive, additive × dominance, domi- nance × dominance, in addition to the additive and dominance gene actions in the expression of these traits. For grain yield, BML-51 was a good general combiner both as grandparent and immediate parent while BML-32 and BML-14 were good general combiners as immediate parent. (BML-51 × BML-6) and (BML-32 × BML-13) had desirable 2-line effects of first and second kind. Crosses viz., (BML-14 × BML-6) × BML-51, (BML-32 × BML-6) × BML-51and (BML-51 × BML-10) × BML-6 were the best performing triplets with desirable 1-line general and 2-line specific effects. Parent order effects *i.e.* the order of lines utilized in three-way crosses were clearly elucidated, the order of in which crosses will be effected for obtaining superior hybrids with high grain yield.

Introduction

Maize is the third most important cereal crop after wheat and rice both in the world and in India. One of the primary goals of most of the maize breeding programs is the development of high yielding hybrids adapted to a wide range of environmental conditions. For breeding of improved varieties with sustainability, comprehensive information about the mechanism controlling the grain yield and its components is essential. Diallel analysis proposed by Griffing (1956) is one of the ways of identifying the genetic nature for quantitative characters of the crops including maize, which help the breeders in formulating the strategy and methods of selection, while the methods of triallel and double cross analysis proposed by Rawlings and Cockerham (1962 a and b) and analysis of Hinkelman (1965) for partial triallel are useful in display of triallel and double cross hybrids in the suitable statistical and genetical analyses to obtain information more clearly. Wright *et al.* (1971) applied triallel analysis method in maize and obtained significant differences for all studied characters. Ponnuswamy *et al.* (1974) developed mathematical models and suitable analysis methods to study the development of lines and quantitative genetics in three-way crosses.

Three way cross was denoted by (A × B) × C has been defined as cross between, line "C" and single cross (A × B). Lines A and B are called as grandparents and line "C" as immediate parent or full parental line (Rawling and Cockerham 1962 a). In the present study an attempt has been made to obtain information on gene actions in controlling yield and yield contributing characters in maize by triallel analysis.

Materials and Methods

Genetic material and field trials

To study the 1-line general, 2-line specific and 3-line specific effects, gene action and order effects of three way crosses, seven promising inbred lines of maize *viz.*, BML-51, BML-32, BML-14, BML-13, BML-10, BML-7 and BML-6 developed at Maize Research Centre, Rajendranagar, Hyderabad were crossed in diallel fashion (Griffing, 1956 Method I Model II) and obtained twenty one crosses during kharif, 2014. Later these F_1's were involved in crosses with inbreds such that no parent appears twice in the same cross and obtained 105 three-way crosses. Similarly, single crosses were involved in diallel set with restriction that only unrelated crosses were involved in crossing programme and obtained 105 double crosses. Single crosses were obtained during kharif 2014 while three-way crosses and double crosses were obtained during rabi 2014-15 at ARS, Karimnagar.

this hand harvested shelled corn of each entry was adjusted to 15.5 moisture in kg ha^{-1} similar to grain yield in bushels per acre at 15.5 moisture (Lauer, 2002).

Statistical data analysis

Mean data over the locations was subjected to triallel analysis (Singh and Chaudhary, 1985) to draw valid conclusions and INDOSTAT software was used for triallel analysis. The criterion of *per se* performance was followed to compare the order effects in three way crosses (Ganga Rao, 1997).

Table 1 - Analysis of variance for grain yield and its components over environments in triallel..

Source of variation	d.f.	Mean squares						
		Ear length	Ear diameter	No.of kernel rows ear^{-1}	No.of kernels row^{-1}	100- grain weight	Shelling percentage (%)	Grain Yield (kg ha^{-1})
Replications	2	27.46**	1.66**	10.85**	38.80**	301.35**	1642.27**	53909820**
1 line order	18	17.08**	0.53**	10.45**	81.40**	58.10**	198.75**	4485829**
1 line general effect of first kind (hi)	18	7.60**	0.04**	6.37**	38.45**	45.50**	120.26**	2099643**
1 line general effect of second kind (gi)	18	21.77**	0.55**	13.99**	103.69**	79.62**	262.09**	5473418**
2 line order	42	1.68*	0.07**	0.61**	7.03*	5.39**	14.33*	1264247*
2 line specific effect of first kind (dij)	42	1.62*	0.08**	0.49**	7.89*	4.62**	13.59*	1390761**
2 line specific effect of second kind (sij)	87	1.57*	0.06**	0.58**	7.58**	3.33*	17.31**	1348900**
3 line specific (tijk)	147	1.52**	0.03**	0.23*	5.66	3.08*	10.34*	917883*
Crosses	312	2.80**	0.08**	1.32**	12.64**	9.08**	30.03**	1358718**
Error	624	0.88	0.01	0.16	4.03	2.10	6.89	628348

a EL: ear length, ED: ear diameter, EW: ear weight, KW: kernel weight per ear, HKW: hundred kernel weight.
b Standard deviation.
c Standard error.
d Genotype. **: $P < 0.01$, ns: not significant.
e Genotype×environment interaction. **: $P < 0.01$, ns: not significant.
f Broad-sense heritability.

During kharif, 2015, the experimental material comprised of seven parents, twenty one single crosses and 105 each three-way and double crosses and eighteen public /private checks were evaluated at three locations viz., MRC, ARI, Rajendranagar, ARS, Karimnagar and RARS, Palem. All these 256 entries were laid out in balanced lattice (16 × 16) in two replications at each location and all the intercultural operations were carried out in accordance with the recommended schedule (Vyavasaya Panchangam, 2015).

Agronomical traits

The data was recorded on ten randomly selected plants for ear length (cm), ear diameter (cm), number of kernel rows ear^{-1}and number of kernels row^{-1}, whereas shelling percentage (%),100- grain weight (g) and grain yield (kg plot^{-1}) was recorded on plot basis. Grain yield (kg plot^{-1}) was corrected for stand variation using the methodology of covariance (Mendes, 2015). Further,

Results and discussion

The analysis of variance for yield and yield contributing characters at individual locations (data not shown) revealed highly significant differences among the genotypes for all studied traits. The parents Vs three-way crosses showed highly significant mean squares for all yield and yield attributing traits. This means that there is a possibility of exploitation of heterosis in three-way crosses.

Combining ability

The triallel analysis across environments (Table 1) showed that 1-line general line effects of both first and second kind, 2- line specific effects of first kind and second kind as well as 3-line specific effects were found significant for all the yield and yield contributing traits except number of kernels row^{-1} in case of 3-line specific effects. This suggested the major role of all three

Table 2 - stimates of general line effects of first (hi) and second kind (gi) for grain yield and its components over environments

Parents	EL	ED	NKRE	NKRR	100-GW	Sh (%)	GY
as grandparent (h_i)							
BML-51	0.16	-0.04**	- 0.42**	0.25	1.70**	0.70**	303.90**
BML-32	0.65**	-0.01	- 0.09*	0.99**	-0.29	1.20**	153.70
BML-14	0.00	-0.01	- 0.27**	-1.11**	1.64**	- 1.00**	16.90
BML-13	- 0.22*	0.00	-0.09*	- 0.27	0.12	0.48**	- 160.50
BML-10	- 0.30**	0.02	0.20**	- 0.54*	- 0.41	- 0.25	- 49.90
BML-7	- 0.25*	0.03*	0.25**	- 0.12	- 0.80**	- 0.72**	- 115.40
BML-6	- 0.04	0.02	0.42**	0.80**	- 1.96**	- 0.42**	- 148.80
SE (hi)	0.10	0.01	0.04	0.22	0.29	0.16	87.72
CD (P=0.05%)	0.21	0.03	0.09	0.44	0.58	0.32	173.80
CD (P=0.01%)	0.27	0.03	0.12	0.58	0.76	0.42	229.88
as parent (g_i)							
BML-51	0.32*	- 0.11**	- 0.67**	0.50	2.52**	1.03**	442.80**
BML-32	1.49**	- 0.04**	- 0.10	2.53**	- 0.37	1.78**	336.30**
BML-14	-0.10	0.01	- 0.60**	-1.98**	4.27**	-0.81**	292.30*
BML-13	-0.25	- 0.13**	-0.16*	0.20	- 0.96*	1.31**	- 373.20**
BML-10	- 0.54**	- 0.02	0.37**	-1.84**	- 1.84**	-0.94**	- 396.90**
BML-7	- 0.40**	0.10**	0.15**	-0.27	- 0.87*	-1.92**	- 300.80**
BML-6	- 0.52**	0.19**	1.00**	0.86**	- 2.77**	-0.46*	- 0.50
SE (hi)	0.13	0.02	0.06	0.29	0.38	0.21	113.24
CD (P=0.05%)	0.27	0.03	0.11	0.57	0.74	0.41	224.37
CD (P=0.01%)	0.35	0.04	0.15	0.75	0.98	0.54	296.76

EL- Ear length; ED- Ear diameter; NKRE- No.of kernel rows ear^{-1}; NKRR- No.f kernels row^{-1}; 100 GW-100 grain weight;
Sh%- Shelling percentage; GY- Grain yield
*: significant at 5% **: significant at 1%

types of epistatic components *viz*., additive × additive, additive × dominance, dominance × dominance, in addition to the additive and dominance gene actions in the expression of these traits. This implies that improvement of these traits will be possible using any breeding procedure which emphasizes epistatic gene effect such as selection in latter generations and/or by using reciprocal recurrent selection. Non-allelic interaction *i.e.*, dominant × dominant (tijk) was insignificant for number of kernels row^{-1}. Similar results were reported by Wright et al. (1971) and Al-Falahy et al. (2014) in maize.

General combining ability

General line effects of first and second kind (hi and gi) for yield and yield contributing traits (Table 2) showed that for ear length BML-32, for ear diameter BML-7, for number of kernel rows ear-1 BML-10, BML-7 and BML-6, for number of kernels row-1 BML-32 and BML-6, for 100-grain weight BML-51 and BML-14, for shelling percentage BML-51, BML-32 and BML-13 and for grain yield BML-51 had positive and significant effects indicating that these parents were good general combiners for their respective traits and could be used both as a grand parents as well as immediate parents in any three-way crosses.

Specific combining ability

Two line specific effects of first kind

The two line specific effects of twenty one crosses first kind for yield and yield contributing characters were presented in Table 3. Cross (BML-51× BML-6) for number of kernel rows ear^{-1} and grain yield and cross (BML-32 × BML-13) for ear length, ear diameters, number of kernel rows ear^{-1} and grain yield had desirable specific effects of first kind (dij). While, crosses (BML-32 × BML-14) for ear length and 100-grain weight, (BML-13 × BML-7) for ear diameter and 100-grain weight, (BML-10 × BML-6) for number of kernels row^{-1} and shelling percentage and (BML-7 × BML-6) for ear length and number of kernel rows ear^{-1} had positive and significant specific effects of first kind (dij).These crosses as grand parents would produce superior three-way crosses for respective traits.

Two line specific effects of second kind

The two line specific effects of twenty one crosses first kind for yield and yield contributing characters were presented in Table 3. Cross (BML-51× BML-6) for number of kernel rows ear^{-1} and grain yield and cross (BML-32 × BML-13) for ear length, ear diameter, number of kernel rows ear^{-1} and grain yield had desirable specific

Table 3 - Two-line specific effects of first kind (i and j as grandparents) for grain yield and its components over environments.

dij	EL	ED	NKRE	NKRR	100-GW	Sh (%)	GY
d12	-0.16	-0.08**	0.03	-0.22	-1.64**	-0.92**	-231.90
d13	0.18	0.01	0.29**	0.63	-0.71	0.06	146.30
d14	0.12	-0.06*	0.06	0.32	-0.82	0.43	-160.00
d15	0.04	-0.01	0.07	-0.72	1.23*	-0.24	-94.90
d16	-0.27	0.06*	-0.16	-0.39	1.24*	0.34	-73.80
d17	0.10	0.08**	-0.30**	0.38	0.70	0.34	414.20*
d23	0.55**	0.00	-0.04	0.67	1.19*	0.32	262.60
d24	0.42*	0.06*	0.06	0.93*	0.61	0.33	543.40**
d25	-0.19	-0.04	0.09	-0.28	-0.62	0.74*	-113.90
d26	-0.30	-0.04	0.00	0.26	-0.38	0.00	-279.30
d27	-0.33	0.10**	-0.14	-1.38**	0.83	-0.47	-181.00
d34	-0.43*	0.00	-0.06	-0.67	-0.27	0.07	-274.50
d35	-0.06	0.06*	0.08	-0.03	0.13	-0.83*	148.90
d36	-0.32	-0.01	-0.22*	-0.82	-0.70	0.20	-306.80
d37	0.07	-0.06*	-0.05	0.21	0.35	0.19	23.40
d45	0.10	-0.08**	-0.22*	0.15	-0.02	0.18	80.50
d46	0.17	0.06*	0.01	0.17	1.19*	-0.10	325.70
d47	-0.37	0.03	0.14	-0.90*	-0.69	-0.91**	-515.20**
d56	0.15	0.08**	-0.01	-0.02	-0.44	-0.58	27.50
d57	-0.04	0.00	-0.02	0.90*	-0.29	0.72*	-48.20
d67	0.57**	-0.15**	0.37**	0.80	-0.91	0.14	306.70
SE (dij)	0.21	0.03	0.09	0.45	0.58	0.32	176.15
CD (P=0.05%)	0.41	0.05	0.17	0.88	1.16	0.64	349.02
CD (P=0.01%)	0.55	0.07	0.23	1.17	1.53	0.84	461.62

1: BML-51, 2: BML-32, 3: BML-14, 4: BML-13, 5: BML-10, 6: BML-7 and 7: BML-6
EL- Ear length; ED- Ear diameter; NKRE- No.of kernel rows ear^{-1}; NKRR- No.of kernels row^{-1}; 100 GW-100 grain weight; Sh%- Shelling percentage; GY- Grain yield
* : significant at 5% ** : significant at 1%

effects of first kind (dij). While, crosses (BML-32 × BML-14) for ear length and 100-grain weight, (BML-13 × BML-7) for ear diameter and 100-grain weight, (BML-10 × BML-6) for number of kernels row^{-1} and shelling percentage and (BML-7 × BML-6) for ear length and number of kernel rows ear^{-1} had positive and significant specific effects of first kind (dij).These crosses as grand parents would produce superior three-way crosses for respective traits.

Two line specific effects of second kind

The two-line specific effects of second kind (sij) were positive and significant in crosses (BML-51 × BML-13) for ear diameter and 100-grain weight, (BML-32 × BML-13) for ear length, 100-grain weight and grain yield, (BML-10 × BML-7) for ear diameter and number of kernel rows ear^{-1} and (BML-10 × BML-6) for ear length, shelling percentage and grain yield (Table 4). Significance of two-line specific effects of second kind indicated that these crosses would be utilized as half parents in production of significant three way crosses. Reciprocal effects (sji) were observed in crosses (BML-10 × BML-7) for ear diameter and number of kernel rows ear^{-1} and (BML-32 × BML-13) for grain yield (Table 5). Reciprocal effects pointed out the maternal effect and to the importance of the order effects of the parents in the three-way cross hybrids.

Considering grain yield, the positive and significant two line specific effect of first kind and second kind in two combinations *viz.*, (BML-51 × BML-6) and (BML-32 × BML-13) showed that they could produce significant effects in the particular order. Hence, these combiners were good specific combiners for grain yield both as grandparents and half parents in three way crosses. The two line order effect is due to interaction between additive × dominance gene effects and all three factors or higher epistatic effects except the all dominance types as reported by Rawlings and Cockerham (1962a).

Three way crosses exhibiting significant three line specific effects (tijk) effects for yield and yield contributing characters were presented in Table (6). For number of kernel rows ear-1 and grain yield (BML-51 × BML-6) × BML-14, for ear diameter and grain yield (BML-32 × BML-10) × BML-7 and for ear diameter and 100-grain weight (BML-32 × BML-10) × BML-51, (BML-10 × BML-6) × BML-7 and (BML-7 × BML-6) × BML-51 had positive and significant tijk estimates. Similarly,

Table 4 - Two-line specific effects of second kind (sij-i as half parent and j as parent) for grain yield and its components over environments.

Sij	EL	ED	NKRE	NKRR	100-GW	Sh (%)	GY
s_{12}	0.22	-0.01	0.36**	0.51	-1.80**	-0.02	-348.90*
s_{13}	-0.12	-0.03	0.02	-0.38	-0.75	-0.28	-167.10
s_{14}	0.36	0.09**	-0.21**	0.51	1.83**	0.40	236.60
s_{15}	-0.40*	0.03	-0.22**	-0.84*	1.90**	-0.48	-67.00
s_{16}	-0.38*	-0.08**	0.10	-0.21	-1.43**	-0.04	-313.00
s_{17}	0.31	0.00	-0.05	0.42	0.26	0.42	659.40**
s_{23}	-0.04	-0.01	-0.24**	-0.27	0.97	-0.16	-204.40
s_{24}	0.41*	0.11	-0.33**	0.10	1.80**	0.18	434.70**
s_{25}	0.03	-0.06**	0.31**	0.45	-2.07**	-0.04	19.80
s_{26}	-0.07	-0.02	-0.16*	0.33	0.38	0.23	118.70
s_{27}	-0.57**	0.02	0.14	-1.12**	-0.47	-0.08	-581.10**
s_{34}	-0.41*	0.02	0.02	-0.30	0.77	-0.16	29.60
s_{35}	0.12	-0.04	0.19*	0.39	-0.76	0.42	-49.20
s_{36}	0.17	0.04	-0.05	0.17	0.24	0.30	255.20
s_{37}	-0.08	0.01	-0.02	0.02	-0.62	-0.42	-221.80
s_{45}	-0.48*	-0.05*	-0.37**	-0.84*	-0.06	0.11	-254.30
s_{46}	0.61**	-0.01	0.04	0.41	-0.56	0.35	104.20
s_{47}	0.23	0.04	0.29**	0.81*	0.11	-0.46	-27.00
s_{56}	-0.31	0.05*	0.19*	-1.34**	0.13	-0.20	-214.70
s_{57}	0.45*	0.02	-0.04	0.85*	0.87	0.76**	432.70**
s_{67}	-0.33	-0.09**	-0.32**	-0.99*	-0.16	-0.21	-262.30
SE (sij)	0.19	0.02	0.08	0.40	0.53	0.29	159.36
CD (P=0.05%)	0.37	0.05	0.16	0.80	1.05	0.58	315.75
CD (P=0.01%)	0.50	0.06	0.21	1.06	1.38	0.76	417.62

1: BML-51, 2: BML-32, 3: BML-14, 4: BML-13, 5: BML-10, 6: BML-7 and 7: BML-6
EL- Ear length; ED- Ear diameter; NKRE- No.of kernel rows ear^{-1}; NKRR- No.of kernels row^{-1}; 100 GW-100 grain weight;
Sh%- Shelling percentage; GY- Grain yield
* : significant at 5% ** : significant at 1%

cross (BML-32 × BML-6) × BML-7 for number of kernel rows row^{-1} and shelling percentage, (BML-14 × BML-6) × BML-13 for ear length and number of kernel rows row-1 and (BML-10 × BML-6) × BML-14 for ear diameter and number of kernel rows ear^{-1} expressed positive and significant tijk effects. The best performance of the triplet for grain yield was (BML-32 × BML-10) × BML-7 (1175.60**) with significant and highest three line specific effect. The other forms of triplets (BML-32 × BML-7) × BML-10 (412.30) and (BML-10 × BML-7) × BML-32 (-493.20) had non significant tijk effects clearly elucidated the order effect of parents in which crossing

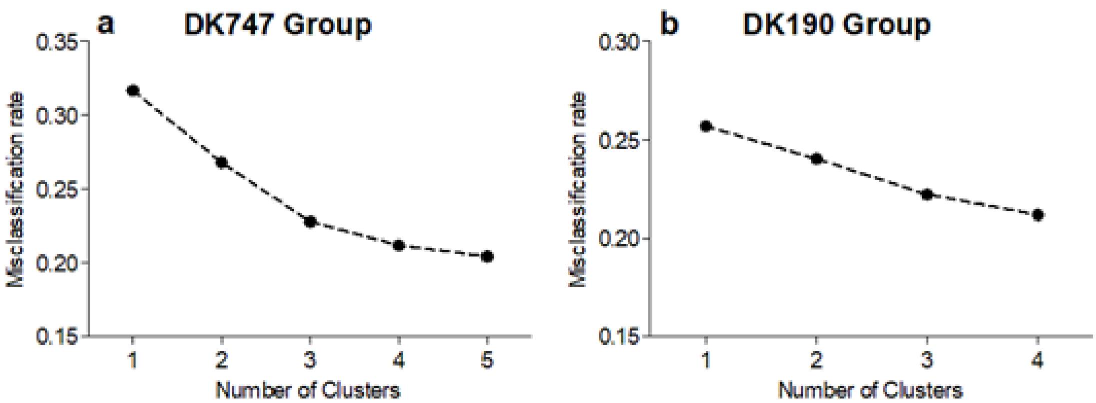

Fig. 3 - Relationship between rate of misclassification and number of clusters obtained with the analysis performed on the data sets of the DK747 group (a) and the DK190 group (b).

Table 5 - Two-line specific effects of second kind (sji-j as half parent and i as parent) for grain yield and its components over environments

Sji	EL	ED	NKRE	NKRR	100-GW	Sh (%)	GY
s_{21}	0.23	-0.02	0.28**	0.51	-0.62	-0.13	212.20
s_{31}	0.09	-0.07**	-0.05	0.01	-0.37	0.39	6.10
s_{41}	-0.34	-0.07**	0.00	-0.42	-0.86	-0.10	-298.30
s_{51}	0.00	-0.02	0.02	-0.50	-0.45	-0.42	-521.60**
s_{61}	-0.30	0.05*	0.04	-0.33	0.71	0.47	59.20
s_{71}	0.31	0.14**	-0.29**	0.73	1.59**	-0.20	542.40**
s_{32}	0.11	0.04	-0.10	-0.28	0.74	-0.54	-20.00
s_{42}	0.16	0.06**	0.02	0.46	0.29	0.99**	396.90*
s_{52}	-0.38*	-0.08**	-0.19*	-0.69	-0.31	-0.65*	-210.30
s_{62}	0.44	-0.02	-0.19*	1.21**	0.71	0.19	322.70*
s_{72}	-0.56**	0.00	0.10	-1.20**	0.37	0.03	-140.30
s_{43}	-0.18	0.03	0.03	-0.41	1.07*	-0.89**	78.60
s_{53}	0.31	0.06**	0.04	1.04*	0.58	0.37	481.00**
s_{63}	-0.16	-0.03	-0.04	-0.75	-0.19	-0.23	-114.10
s_{73}	0.19	-0.01	0.19*	0.76	-1.68**	1.19**	-73.90
s_{54}	-0.07	-0.02	-0.02	0.64	-0.82	0.14	32.90
s_{64}	-0.22	-0.03	0.24**	-0.48	-1.30*	-0.70*	-269.10
s_{74}	-0.08	-0.16**	0.30**	-0.46	-2.28**	0.13	-464.80**
s_{65}	0.57**	0.12**	0.27**	1.33**	0.22	0.48	263.70
s_{75}	0.15	0.01	-0.17*	-0.48	0.76	-0.50	87.00
s_{76}	-0.02	0.03	-0.12	0.65	1.24*	-0.64*	49.60
SE (sji)	0.19	0.02	0.08	0.40	0.53	0.29	159.36
CD (P=0.05%)	0.37	0.05	0.16	0.80	1.05	0.58	315.75
CD (P=0.01%)	0.50	0.06	0.21	1.06	1.38	0.76	417.62

1: BML-51, 2: BML-32, 3: BML-14, 4: BML-13, 5: BML-10, 6: BML-7 and 7: BML-6
EL- Ear length; ED- Ear diameter; NKRE- No.of kernel rows ear^{-1}; NKRR- No.of kernels row^{-1}; 100 GW-100 grain weight; Sh%- Shelling percentage; GY- Grain yield
* : significant at 5%   ** : significant at 1%

will be made to attain best performance triplet. All the above mentioned triplets had either significant 1-line general line effects of first and second kind or 2- line specific effects of first kind or second kind or 3-line specific effects. Hence one can conclude that the superiority of the triplets is mainly due to (1) two of three parent showing better general line effects (2) one cross showing better two line specific effect and/or (3) the interaction might be due to additive × additive and additive × dominance among the three lines used in making the triplet (Joshi and Sharma, 1984).

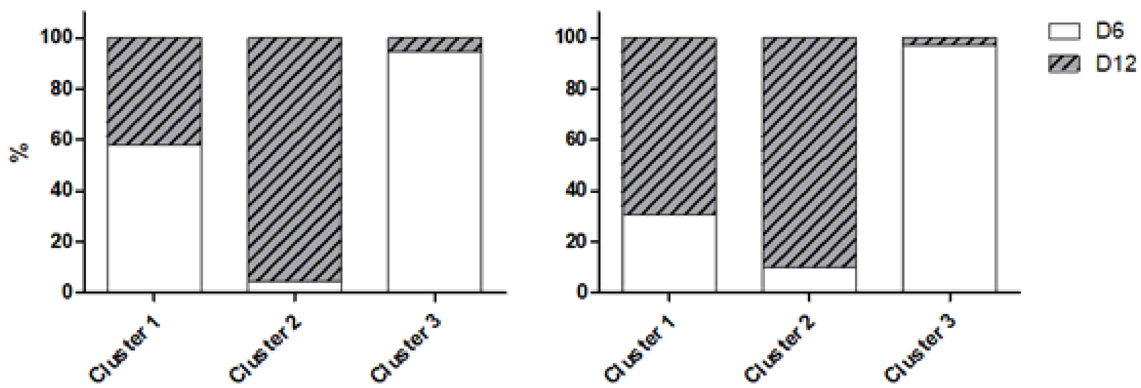

Fig. 4 A - Relationship between rate of misclassification and number of clusters obtained with the analysis performed on the data sets of the DK747 group (a) and the DK190 group (b).

Table 6 - Significant three-line specific effects (tijk) grain yield and its components over environments

S.No.	tijk	EL	ED	NKRE	NKRR	100-GW	Sh (%)	GY
1	(12)3	0.09	0.01	-0.12	-0.45	2.33*	0.70	272.70
2	(12)4	0.38	-0.01	0.46**	1.21	-0.35	0.48	525.40
3	(12)5	1.07**	0.00	-0.21	1.52	1.44	0.77	278.50
4	(13)5	0.48	0.13**	0.15	0.47	1.97	-1.13*	25.60
5	(13)6	0.26	0.06	-0.25	-0.57	1.53	0.45	644.50*
6	(14)5	-0.65	0.00	0.32*	-1.10	-1.38	-0.21	180.60
7	(14)6	0.62	0.08	0.01	1.33	3.19**	1.07	546.60
8	(15)2	0.60	-0.01	0.32*	-0.33	-0.07	0.61	138.10
9	(15)4	0.48	0.12**	-0.12	0.56	0.78	-0.87	247.50
10	(16)3	0.54	0.08	0.33*	1.30	0.50	0.40	868.00**
11	(16)7	0.05	0.05	0.34*	-0.22	-2.22*	-0.34	-120.80
12	(17)4	-0.52	0.09*	-0.08	-0.72	0.13	0.60	302.70
13	(17)5	-0.15	-0.05	0.08	0.73	-1.45	1.17*	-40.10
14	(25)1	0.21	0.14**	-0.07	-0.16	2.60*	-0.10	-27.20
15	(25)6	0.58	0.09*	0.08	1.06	0.54	0.71	1175.10**
16	(25)7	-0.10	-0.10*	0.42**	-0.21	-2.34*	0.70	-501.20
17	(26)5	0.38	0.03	0.29	0.47	0.51	1.21*	412.30
18	(26)7	0.26	0.08	-0.19	-0.01	2.22*	-0.58	381.60
19	(27)4	-0.82*	0.13**	0.26	-1.87*	-0.36	-0.71	-196.90
20	(27)6	0.41	-0.07	-0.04	1.59*	0.30	1.58**	263.30
21	(35)7	0.38	0.10*	0.09	-0.40	0.93	0.08	507.70
22	(36)2	0.93*	0.07	-0.02	0.53	1.22	-0.28	392.40
23	(36)4	-0.23	0.15**	0.16	-0.08	-0.31	-0.38	395.00
24	(37)1	-0.24	0.09*	0.29	0.00	0.09	0.04	494.90
25	(37)4	1.35**	-0.05	-0.08	2.08**	1.43	0.14	286.40
26	(45)1	-0.16	0.06	0.00	0.35	1.51	0.24	628.30*
27	(45)2	0.77*	0.02	0.12	1.51	-0.06	0.09	186.80
28	(46)7	0.21	0.04	0.24	0.65	1.49	1.39*	492.30
29	(56)4	-0.28	0.03	0.35*	-0.03	-0.42	0.86	227.20
30	(57)3	0.26	0.11*	0.31*	1.10	-0.78	1.00	545.70
31	(57)6	0.20	0.15**	-0.14	-0.44	2.05*	-1.12	169.50
32	(67)1	-0.17	0.17**	-0.17	-1.05	2.58*	-0.18	-116.90
33	(67)5	0.49	0.18**	0.14	1.36	0.19	0.16	525.40
SE (tijk)		0.37	0.05	0.16	0.79	1.04	0.57	312.64
CD (P=0.05%)		0.74	0.09	0.31	1.57	2.05	1.13	619.45
CD (P=0.01%)		0.97	0.12	0.41	2.07	2.71	1.50	819.30

1: BML-51, 2: BML-32, 3: BML-14, 4: BML-13, 5: BML-10, 6: BML-7 and 7: BML-6

EL- Ear length; ED- Ear diameter; NKRE- No.of kernel rows ear^{-1}; NKRR- No.of kernels row^{-1}; 100 GW-100 grain weight; Sh%- Shelling percentage; GY- Grain yield

*: significant at 5% **: significant at 1%

Order effects of the parents in three way crosses

Criterion of per se performance was followed to compare the order effects in three way crosses (Table 7).105 three way crosses were classified in to thirty five groups of three crosses each. Of the thirty five groups, twenty six groups had three-way crosses with particular order arrangement had superior per se performance in that particular group. For example in the group 2, three-way cross (BML-51 × BML-32) × BML-13 had superior per se performance with a grain yield of 8066 kg ha^{-1} than other arrangements namely (BML-51 × BML-13) × BML-32 with 7049 kg ha^{-1} and (BML-32 × BML-13) × BML-51 with 7553 kg ha^{-1}.However, the parents involved in the groups *viz.*, 1,3,6,7,11,17,19,28 and 35 had shown the comparable performance in three-way crosses for all the three types of arrangement in that specific group. Out of 105 three way crosses, four crosses belonging to various groups expressed superior performance. They are namely (BML-14 × BML-6) × BML-51, (BML-32 × BML-6) × BML-51, (BML-51 × BML-10) × BML-6 and (BML-13 × BML-7) × BML-32 and these crosses had BML-51 either as grand parent or immediate parent or BML-32 as immediate parent or

Table 7 - Order effects of the parents for grain yield (kg ha^{-1}) in three way crosses over environments.

Crosses	Grain yield (kg ha^{-1})	Crosses	Grain yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Crosses	Grain yield (kg ha^{-1})	Crosses	Grain yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Grain yield (kg ha^{-1})
	Group-1		Group-8		Group-15		Group-22		Group-29	
1	(12)3	7436	(13)6	7770	(16)7	7408	(24)7	6735	(35)6	6473
2	(13)2	7610	(16)3	8011	(17)6	6999	(27)4	6241	(36)5	6517
3	(23)1	8046	(36)1	6985	(67)1	7987	(47)2	6920	(56)3	7533
	Group-2		Group-9		Group-16		Group-23		Group-30	
1	(12)4	8066	(13)7	7996	(23)4	7755	(25)6	7785	(35)7	7851
2	(14)2	7049	(17)3	7229	(24)3	8137	(26)5	7075	(37)5	6542
3	(24)1	7553	(37)1	8395	(34)2	7235	(56)2	6835	(57)3	8015
	Group-3		Group-10		Group-17		Group-24		Group-31	
1	(12)5	7077	(14)5	6463	(23)5	6914	(25)7	6357	(36)7	5387
2	(15)2	7091	(15)4	7320	(25)3	7298	(27)5	5824	(37)6	6682
3	(25)1	7113	(45)1	7138	(35)2	7308	(57)2	6855	(67)3	6893
	Group-4		Group-11		Group-18		Group-25		Group-32	
1	(12)6	5734	(14)6	7038	(23)6	7093	(26)7	6314	(45)6	5686
2	(16)2	7311	(16)4	6554	(26)3	6018	(27)6	6972	(46)5	6099
3	(26)1	7601	(46)1	7127	(36)2	7643	(67)2	7718	(56)4	6497
	Group-5		Group-12		Group-19		Group-26		Group-33	
1	(12)7	7258	(14)7	7660	(23)7	7040	(34)5	5903	(45)7	7218
2	(17)2	7603	(17)4	7288	(27)3	7176	(35)4	6831	(47)5	5878
3	(27)1	8378	(47)1	6861	(37)2	6542	(45)3	7789	(57)4	5850
	Group-6		Group-13		Group-20		Group-27		Group-34	
1	(13)4	6474	(15)6	6193	(24)5	7069	(34)6	7075	(46)7	7269
2	(14)3	6785	(16)5	6487	(25)4	6733	(36)4	6394	(47)6	5867
3	(34)1	6641	(56)1	7144	(45)2	7597	(46)3	7464	(67)4	5675
	Group-7		Group-14		Group-21		Group-28		Group-35	
1	(13)5	6997	(15)7	8349	(24)6	7482	(34)7	6115	(56)7	7036
2	(15)3	7470	(17)5	7169	(26)4	6396	(37)4	6387	(57)6	6474
3	(35)1	6874	(57)1	6534	(46)2	8214	(47)3	6303	(67)5	7539

SEm±: 647.2

1: BML-51, 2: BML-32, 3: BML-14, 4: BML-13, 5: BML-10, 6: BML-7 and 7: BML-6

BML-51 and BML-6 as half parents. It clearly indicated that there is possibility of getting promising three way crosses by involving good general combiners as grand parents or immediate parents and good specific combining single crosses as half parents. Further, order of the parents in the three-way crosses also indicated that per se performance was not related to percentage of genetic contribution either by the high yielding grand parents (25% each) or by the immediate parent (50%). In essence, the crosses belonging to the same group showed variable per se performance despite the commonality of parents involved. This clearly brings out that order or position of the parents in multi-way crosses is one of the crucial factors in determining the performance and must be considered while planning the hybridization programmes.

Components of genetic variance

Components of variance for yield and yield contributing traits were presented in Table (8).Components of variance for ear length and ear diameter indicated that additive × dominance component was highest

Table 8 - Genetic components of variance for yield and yield contributing characters in maize over pooled environments.

Components	Ear length	Ear diameter	Number of kernel rows ear^{-1}	Number of kernels row^{-1}	100- grain weight	Shelling percentage	Grain yield (kg ha^{-1})
Additive	0.740	-0.003	0.537	2.881	9.574	3.800	-15781.910
Dominance	-2.396	-0.086	-0.024	-5.638	-11.148	-0.776	-1434512.050
Additive × additive	0.379	0.045	0.137	3.115	2.931	-0.149	334636.250
Additive × dominance	7.250	0.124	0.097	6.174	22.959	0.979	3859387.740
Dominance × dominance	0.072	0.020	0.124	2.499	2.365	2.334	-190696.160

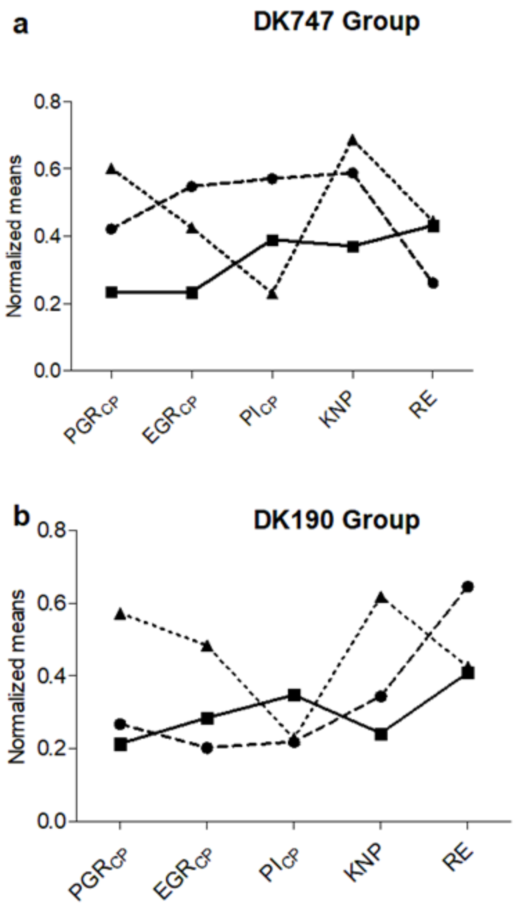

Fig. 5 - Normalized mean values of secondary traits at each cluster, for DK747 group (a) and DK190 group (b). For each trait normalization was carried out by considering a mean of zero and a standard error of 1 in order to compare at each cluster, the weight of traits measured with different units

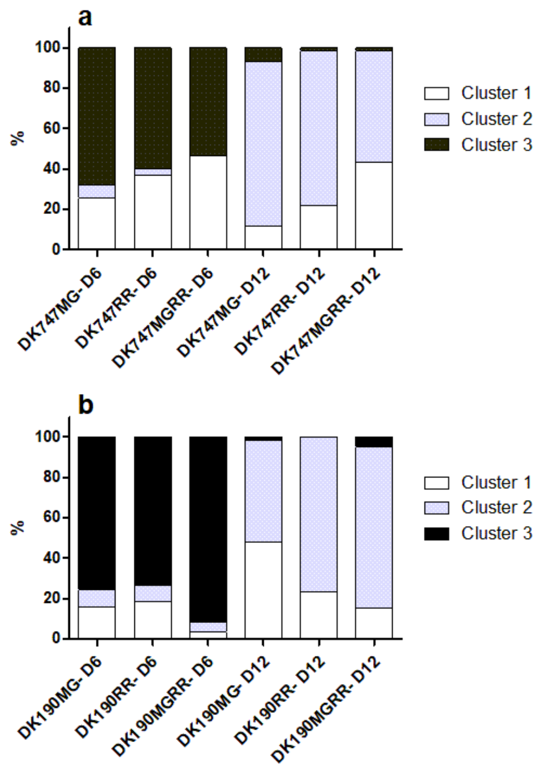

Fig. 6 - Percentage of maize plants of the different versions of the DK747 group (a) and DK190 group (b) cultivated at two densities (D6 and D12) classified within the three clusters described in Fig. 4 and 5.

in magnitude while dominance component was negative for ear length and ear diameter and additive component was negative for ear diameter. Additive component was highest for number of kernel rows ear^{-1} and additive × dominance epistatic component was highest followed by additive × additive for number of kernels row^{-1} (Johnson, 1973). Dominance component was negative for both the traits. For 100-grain weight, additive × dominance epistatic effect was highest in magnitude followed by additive component, whereas additive component was highest followed by dominance × dominance epistatic effect in case of shelling percentage. Dominance component was negative for 100- grain weight and dominance and additive × additive epistatic components were negative for shelling percentage. With respect to grain yield, additive × dominance epistatic component was highest in magnitude followed by additive × additive component and additive and dominance components were negative (Stuber and Moll, 1974 ; Al-Falahy et al., 2014). It means that non fixable component of genetic variance was playing major role in governing the character, hence heterosis breeding may be adopted for the character. Thus predominance of epistatic components of genetic variance for grain yield has to be kept in mind while formulating the breeding procedures for improvement of the trait. Thus, triallel analysis clearly envisaged its advantage over diallel analysis by giving additional information on magnitude of all types of epistatic components and also on order of parents to be crossed in three-way crosses for obtaining high yielding combinations.

Conclusions

(BML-14 × BML-6) × BML-51, (BML-32 × BML-6) × BML-51and (BML-51 × BML-10) × BML-6 were found to be best performing triplets for grain yield with superior per se and had BML-51, a parent with desirable 1-line general effects of first and second kind suitable both as grandparent and immediate parent in three-way crosses. Further, (BML-32 × BML-6) × BML-51 had desirable dij effects for ear diameter and (BML-51 × BML-10) × BML-6 had desirable dij effects for 100 grain weight and desirable sij effects for grain yield. Hence, the potentiality of these triplets could be exploited as an alternative to single crosses to overcome problems arising in seed production, biotic and abiotic stresses.

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