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Effect of cytoplasm on combining ability and yield attributes in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract

The effect of cytoplasm on productivity and combining ability for grain yield and its contributing traits was studied in 144 hybrids. Six male sterile (A) lines 81A and HMS 8A (A_1), Pb3l3A (A_2), Pb402A (A_3), $81A_4$, $81A_5$ representing five different cytoplasm systems and their corresponding maintainer (B) lines were crossed with 12 restorer (R) lines in a line x tester design. The 24 parents (A+B and R) and 144 crosses were grown separately in contiguous block in randomized block design with two replications in six environments, three each (E1, E2, E3) and (E4, E5, E6) during 2000 and 2001, respectively. Analysis of variance revealed significant differences among genotypes, parents, lines (A, B), testers, hybrids (A x R, B x R). The differences due to A vs. B and A x R vs. B x R crosses were highly significant for grain yield/plant (g), harvest index (%) and growth rate (g/plant/day). Cytoplasmic effects were estimated by comparing A x R and B x R hybrids combination. Both positive and negative cytoplasmic effects were observed for all the four characters studied. The (A x R vs. B x R) x E component of variance exhibited significance for all the four characters. The effects were modified by environment. These were more pronounced for grain yield, 500-grain weight and harvest index, and positive cytoplasmic effects exceeded than the negative ones. For growth rate negative cytoplasmic effects were preponderant and significant only in one environment which is due to cytoplasm and nuclear genome interaction. Effect of cytoplasm was more or less equally pronounced on general combining ability effects of parents and specific combining ability of crosses. Array mean performance of 81A cytoplasmic iso-hybrids indicated that all the three cytoplasms have same potential, therefore, any of these cytoplasms can be used in hybrid breeding.

Key words: Cytoplasmic effects, combining ability, pearl millet

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br. emend Stuntz] is a bisexual, protogynous highly cross pollinated grass. Cytoplasmic-genic male sterility (CMS) is a maternally inherited phenotype, characterized by an inability to produce viable pollen, while female fertility and vegetative development are unaffected. Fleming *et al*. [1] were the first to point out the importance of cytoplasmic effects on agronomic characters in maize.

Burton [2] first reported the CMS in pearl millet. The use of CMS in pearl millet paved the way for grain yield augmentation with the development and release of first grain hybrid HB-I (Tift 23 A x BIL-3B) by Athwal [3]. Since then the higher productivity (75-100%) of CMS based hybrids over local varieties [4] attracted the farmers to cultivate them on large scale, which led to increased incidence of downy mildew caused by *Sclerospora graminicola*. A_1 male sterile cytoplasm used in all the hybrids released in India, was apprehended to be responsible for increase in disease [5]. Potential vulnerability of the hybrid industry to disease, insect-pest epidemics due to cytoplasmic uniformity, as witnessed in case of southern leaf blight (*Bipolaris maydis*) epidemic on the Texas cytoplasm-based corn hybrid in United States [6] has generally been put forth as a strong argument for cytoplasmic diversification of hybrid cultivars. Different sources of MS cytoplasm such as A_2, A_3 [7], Gero, Maiwa [8], A_4 [9] and A_5 [10] have been discovered. Recently Kumar and Sagar [11] compared five systems of male sterility in pearl millet and did not find the cytoplasm to be associated with downy mildew susceptibility.

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Influence of A_1 cytoplasm on grain yield and yield components have been reported [12, 13]. However, cytoplasmic effects are modified by interaction with environments [14]. Near iso-nulcear polycytoplasmic lines differed significantly in mean value for a few traits e.g. plant height, leaf length and peduncle length, but the differences for combining ability were more pronounced [15]. Comparable grain yield levels of the hybrids based on A_2, A_3 and *violaceum* sources of cytoplasms than the A_1 source hybrids have been reported [16]. The availability of an identical genome in different cytoplasm provides a unique opportunity for the critical analysis of the role of cytoplasm. Cytoplasm influences dry matter yields, however, further studies are needed to distinguish between cytoplasmic and cytoplasmic-nuclear effects [17].

The present study reports the effect of five different cytoplasms including A_2 (Pb313A_2), and A_3 (Pb 402A_3) and three cytoplasms in identical genome (81B) i.e. 81A_1 including widely used cytoplasm, 81A_4 and 81A_5 in the sterile and normal background on the grain yield and its important contributing characters in pearl millet.

Materials and methods

The material for the present study consisted of six male sterile (A) lines from five systems of cytoplasmic-genic male sterility *viz.*, two male sterile lines from A_1 system (MS81A_1, HMS8A_1) and one each from A_2 (Pb3l3A_2), A_3 (Pb402A_3), A_4 (MS81A_4) and A_5 (MS8IA_5), their corresponding maintainer (B) lines 81B_1, HMS 8B_1, Pb3l3B_2, Pb402B_3, 81B_4 and 81B_5 and twelve restorer (R) lines *viz.*, H90/4-5, 77/833-2, G73-107, 77/245, 77/273, CSSC 46-2, ISK48, ICR161, 77/180, 78/711, H77/28-2 and Raj. 42.

Six male sterile lines and their corresponding six maintainer lines were crossed as paired crosses with twelve restorer lines in a line x tester design at ICRISAT, Hyderabad, during off season (January-April, 2000). The resultant 144 hybrids and their 24 parents were grown separately in contiguous blocks in randomized block design with two replications in six environments, three each (E1, E2, E3) during *kharif* 2000 and (E4, E5, E6) during *kharif*-2001 at Research Farm, Bajra Section, Department of Plant Breeding, CCS HAU, Hisar (Table 1). The unratoon early sown crop and ratoon crop was sown on 5th June in 2000 and 25th June in 2001. The ratoon crop was cut at a height of approximately 12 cm on 14th July 2000 and 5th August 2001, and left to regenerate. The unratoon late sown crop was sown on 14th July 2000 and 5th August 2001. The plot size was 2.5 m long two rows spaced 45 cm apart with 10 cm intra-row spacing. All the recommended agronomic practices were followed to raise a good crop. Five competitive plants were taken randomly in each plot in each replication and observations were recorded on 500-grain weight (g), grain yield/plant (g), harvest index (%) = (grain yield/biological yield) x 100 [18], growth rate (g/plant/day) = dry fodder yield/plant (g)/(days to 50 % flowering + 10) [19], were recorded at maturity. The mean values for each trait in each replication in all environments were used in statistical analysis. The cytoplasmic effects were estimated by comparing means obtained from, A x R (male sterile line x restorer) and B x R (maintainer line x restorer) cross combination. Critical Difference (CD) values were calculated for test of significance.

The analysis of variance for randomized block design was carried out for each character in each of the environments according to Federer [20] and

Table 1. Detail of the created six environments for testing genotypes and environmental means for four characters

Year	Environment	Date of sowing	Environment means			
			Grain yield/ plant (g)	500-grain weight (g)	Harvest index (%)	Growth rate (g/plant/day)
2000	E1	Planting 5th June (unratoon early sown crop)	30.94	4.27	28.61	1.25
	E2	Planting 5th June and crop cut on 14th July about 12cm above ground (ratoon)	26.11	4.06	26.03	0.86
	E3	Planting 14th July (unratoon late sown crop)	23.19	4.41	27.30	1.07
2001	E4	Planting 25th June (unratoon early sown crop)	29.17	4.23	28.17	1.06
	E5	Planting 25th June and crop cut on 5th August about 12cm above ground (ratoon)	24.53	3.96	28.51	0.71
	E6	Planting 5th August (unratoon late sown crop)	24.65	4.25	27.19	1.08

combined analysis of variance was performed as per the model given below:

$$\mathbf{Y}_{ijklm} = \boldsymbol{\mu}+\mathbf{g}_{ij}+\mathbf{e}_{kl}+(\mathbf{ge})_{ijkl}+\mathbf{r}_{m(lk)}+\boldsymbol{\varepsilon}_{ijklm}$$

Further

$$\mathbf{g}_{ji} = \mathbf{p}_i+\mathbf{t}_j + (\mathbf{pt})_{ij} = \mathbf{p}a_i+\mathbf{p}b_i + \mathbf{t}_j + (\mathbf{pt})a_{ij} + (\mathbf{pt})b_{ij}$$

$$\mathbf{e}_{kl} = \mathbf{y}_k + \mathbf{d}_l + (\mathbf{yd})_{kl}$$

$$(\mathbf{ge})_{ijkl} = (\mathbf{pe})_{ikl} + (\mathbf{te})_{jkl} + (\mathbf{pt})_{(ij)(kl)}$$

$$= (\mathbf{pe})a_{ikl} + (\mathbf{pe})b_{ikl} + (\mathbf{te})_{jkl} + (\mathbf{pt})a_{(ij)(kl)} + (\mathbf{pt})b_{(ij)(kl)}$$

i = 1, 2,...........,12 (lines)

a = 1, ..., 6

b = 1,..........., 6

j = 1,2,..............,12 (testers)

k = 1, 2, (years)

l = 1,........, 4 (dates)

m = 1, 2 (replications)

Where

g = genotypes; e = environments; r = replications; p = parents; t = tester; y = year; d = date

The combining ability analysis was performed following Kempthorne [21].

Results and discussion

The combined analysis of variance presented in Table 2 revealed significant differences between environments, genotypes i.e. parents, lines (A, B), testers, hybrids-(A x R, B x R) and also their interaction with environments for the characters studied. The A- and B- lines exhibited significantly different performance for all the characters studied. The A vs. B contrast exhibited significant differences for all the four characters. The differences due to A x R vs. B x R crosses were highly significant for grain yield and harvest index, on pooled basis, however, these differences were significant in individual environment for 500-grain weight except in E4 and for growth rate only in E6 (data not presented). This indicated that the cytoplasmic effects were important for expression of these characters. The cytoplasmic effects for all the characters were influenced by environments as (A x R vs. B x R) x E component of variance was also significant for all the characters. Significant cytoplasmic effects-total, positive and negative for the four traits are presented in Fig. 1 and a few selected crosses in Table 3.

Grain yield

The cytoplasmic effects were pronounced for grain yield in four of the six environments except E4 and E5. A high number, 139 (36, 36, 27, 40) of 288 (72 comparisons in each of the four environments) possible comparisons, exhibited statistically significant cytoplasmic effects. Seventy eight of 139 cross combinations showed positive and 61 negative significant cytoplasmic effects. The positive significant cytoplasmic effects were preponderant in E1, E2 and E3. The magnitude of cytoplasmic effects was variable in different crosses. The hybrid combinations *viz*., Pb313A_2 x G73-107 vs. Pb313B_2 x G73-107, 402A_3 x 77/273 vs. Pb402B_3 x 77/273 and 81A_4 x CSSC 46-2 vs. 81B_4 x CSSC 46-2 exhibited positive significant cytoplasmic effects in most of the environments. Out of 72 cross comparisons in each environment, the number of crosses showing significant positive and significant negative cytoplasm effects, respectively (shown in paranthesis) over the environments were preponderant in hybrids of Pb313A_2/B_2 (16, 16), 81A_1/B_l (14, 10), 81A_5/B_5 (14, 11), 81A_4/B_4 (13, 8) and Pb402A_3/B_3 (12, 3) but in case of HMS8A_l/B_1 hybrids (9, 13) number of significant negative effects exceeded the positive one.

A number of paired crosses showed significant positive cytoplasmic effects in one environment and significant negative cytoplasmic effects in other environments e.g. the cross 8A_1 x G73-107 vs. 8B_1 x G73-107 (Table 3). This implies that cytoplasmic effects were the result of interaction between the cytoplasm and nuclear genome and were modified in different environments as also reported in rice [22], pearl millet [14] and in sorghum [23].

500-seed weight

Seed size was affected by significant cytoplasmic effects in five of the six environments except E4. Of 182 significant cytoplasmic effects 95 (20, 20, 31, 16, 8) were positive and 87 (11, 23, 28, 22, 3) negative of the 360 (72 crosses in each of five environments) possible comparisons. The paired hybrids 8A_1 x 77/245 vs. 8B_1 x 77/245 and Pb402A_3 x 77/273 vs. Pb402B_3 x 77/273 showed significant positive cytoplasmic effects in most of the environments. In general the paired crosses of all the lines depicted significant positive as well as significant negative cytoplasmic effects in all the environments. On overall basis the positive effects exceeded in crosses of 81A_1/B_1 (16, 13) 8A_1/B_1 (17, 10), 402A_3/B_3 (16, 15) and negative effects were more pronounced in 8A_4/B_4 (11, 17) crosses.

Table 2. Combined analysis of variance for some quantitative characters in different environments during two years

Source of variation	d.f.	Mean sum of squares			
		Grain yield/plant (g)	500-grain weight (g)	Harvest index (%)	Growth rate (g/plant/day)
Reps. in environments	6	54.62	0.14	6.3	0.037
Environments (E)	5	3036.23**	8.63**	329.3**	12.609**
Year	1	200.90**	4.54**	206.9**	6.838**
Date	2	6938.06**	18.69**	288.5**	26.245**
Year x date	2	552.08**	0.62**	431.3**	1.860**
Genotypes (G)	167	529.66**	3.83**	76.4**	0.441 **
Parents (P)	23	67.83**	1.77**	52.6**	0.066**
Lines	11	47.48**	1.65**	65.6**	0.029*
A lines	5	68.01**	1. 18**	103.8**	0.031
B lines	5	27.73**	1.75**	38.8**	0.009
A vs B	1	43.56*	3.46**	8.3*	0.121**
Testers	11	84.31 **	1.99**	34.7**	0.110**
Lines vs Testers	1	110. 39**	0.72**	106.6**	0.001
Hybrids (H)	143	242.39**	2.44**	66.0**	0.119**
P vs H	1	52231.59**	250.50**	2098.6**	55.07**
A x R hybrids	71	227.21 **	2.53**	53.2**	0.135**
B x R hybrids	71	260.29**	2.38**	78.3**	0.105**
A x R vs B x R	1	49.51 **	0.03	108.8**	0.047
G x E	835	58.86**	0.38**	17.4**	0.062**
P x E	115	14.34**	0.37**	19.0**	0.026**
H x E	715	64.84**	0.38**	16.8**	0.062**
(P vs H) x E	5	228.59**	1.45**	64.7**	0.992**
A x R x E	355	60.54**	0.37**	16.6**	0.058**
B x R x E	355	68.93**	0.40**	17.2**	0.066**
(A x R vs B x R) x E	5	79.84**	0.49**	8.4**	0.037*
Error	1002	7.01	0.05	2.1	0.014

*Significant at 5% level, **Significant at 1 % level

Harvest index

Cytoplasmic effects were recorded for harvest index in E1, E2, E3 and E5 environments. Out of 288 (72 comparisons in each of the four environments) possible comparisons 129 (38, 26, 33, 32) exhibited significant cytoplasmic effects. The number of significant positive and significant negative cytoplasmic effects was 85 (26, 18, 20, 21) and 44 (12, 8, 13, 11) of 129 paired crosses, respectively. The number of significant positive effects was 19 each in crosses of $313A_2/B_2$ and $Pb402A_3/B_3$, and 13 each in crosses of $81A_1/B_1$ and $81A_4/B_4$. The lowest number of significant negative effects was in crosses of $81A_1/B_1$ (3) and highest in crosses of $8A_1/B_1$ (10).

Growth rate

The cytoplasmic effects were significant for growth rate in E6 only. Of the 72 paired cross comparisons 30 showed significant cytoplasmic effects including 10 with positive and 20 with significant negative effects (Fig. 1). The number of significant positive effects was highest in crosses of $81A_5/B_5$ followed by Pb $402A_3/B_3$. Maximum number of significant negative effect was noted in crosses of $Pb313A_2/B_2$.

Array mean performance of 81A iso-hybrids

Array mean performance of 81A iso-hybrids is presented in Table 4. In a number of cases sterile cytoplasm (A) hybrids performed better than fertile cytoplasm (B)

Table 3. Cytoplasmic effects of a few selected crosses for four quantitative characters in different environments during two years

Crosses	Grain yield/plant (g) (g1plant/day)				500-grain weight (g)					Harvest index (%)				Growth rate (g/plant/day)
	E1	E2	E3	E6	E1	E2	E3	E5	E6	E1	E2	E3	E5	E6
$81A_1$ x 77/245 vs. $81B_1$ x 77/245	9.0*	–8.7*	9.1*	–14.4*	0.5*	0.0	0.4*	0.4*	0.6	–0.7	–8.6*	4.3*	5.2*	–0.17
$8A_1$ x G73-107 vs. $8B_1$ x G73-107	–8.7*	6.4*	2.7	–15.0*	–0.3	0.1	0.1	0.4*	–0.4	–4.7*	4.6*	–1.5	–0.7	–0.30*
$313A_2$ x G73-107 vs. $313B_2$ x G73-107	–8.8*	–3.6	9.5*	–18.0*	–0.2	–0.2	0.7*	–0.8*	–0.3	0.6	–3.9*	–0.6	3.8*	–0.48*
$402A_3$ x 77/273 vs. $402B_3$ x 77/273	10.3*	9.4*	9.1*	4.5	0.4*	0.6*	0.2*	0.9*	–0.5	0.3	7.1*	5.8*	–2.2	0.22*
$81A_4$ x CSSC 46-2 vs. 81 B_4 x CSSC 46-2	13.1*	5.5*	–3.5	5.4*	0.3	–1.0*	0.3*	–0.3	0.0	6.5*	5.0*	0,0	3.3*	0.08
$81A_5$ x G73-107 vs. 81 B_5 x G73-107	16.7*	–0.9	–0.7	9.1*	0.5*	–0.1	0.9*	0.2	0.4	1.9	-0.3	–0.7	–2.2	0.43*
CD at 5%	4.7	5.4	4.6	5.3	0.4	0.3	0.2	0.4	0.7	2.0	3.4	3.0	2.7	0.2

*significant at 5% level
EI & E4 = unratoon early sown crop, E2 & E5 = ratoon crop, E3 & E6 = unratoon late sown crop

hybrids. The iso-hybrids $81A_4$ vs $81B_4$ in EI and E6; $81A_5$ vs. $81B_5$ in EI and E4 and $81A_1$vs $81B_1$ in E5 performed better for grain yield. None of the $81A_1$ system hybrids ($81A_1$, $81A_4$, $81A_5$) uniformly and significantly excelled between them except for the differential responses. However, the hybrids of $81A_5$ were significantly better than $81A_4$, $81A_1$ and $81A_4$ better than $81A_1$ for grain yield and harvest index in EI and E4 and also on pooled basis. The hybrids of $81A_1$ significantly performed superior to $81A_4$ hybrids for 500-grain weight and harvest index in E3 and E4 and also on pooled basis. This shows that all the three cytoplasms have same potential, therefore, any of these cytoplasms can be used in hybrid breeding.

Cytoplasmic effects on combining ability

Cytoplasmic effects on general combining ability (GCA) of parents and specific combining ability (SCA) of some selected crosses are presented in Table 5. Of the thirty six pairs of comparisons of twelve lines (six A, six B) in six environments, fifteen for grain yield, seventeen for harvest index, ten for 500-grain weight and twelve for growth rate depicted significant differences. None of the parents showed significant cytoplasmic effect on general combining ability for any of the characters studied across all the six environments which could be due to cytoplasmic environment interaction. Only one parent $81A_4/81B_4$ exhibited consistent positive cytoplasmic effects on GCA for harvest index, though significant only in three environments. Similarly parents $Pb313A_2/313B_2$, $Pb402A_3/402B_3$ also expressed significant positive cytoplasmic effects on GCA effects in two or more environments for grain yield and harvest index and $81A_5/8lB_5$ for harvest index. It showed that when either of the lines i.e. A or B is used as female gave higher performance in hybrids, though this was not true for other characters studied. The negative cytoplasmic effect on GCA was noted for lines $81A_1/81B_1$, $8A_1/B_1$ for grain yield, $81A_1/81B_1$, $313A_2/313B_2$, $81A_4/81B_4$ for 500-grain weight and $8A_1/81B_1$, $402A_3/402B_3$ for growth rate having significant negative values in two or more numbers of environments. It also exhibited that A-lines performed better in hybrids. The effect of cytoplasm on SCA of crosses was almost similar for three yield characters i.e., almost equal number of crosses 189,187 191 and exhibited significance for grain yield, 500-grain weight and harvest index, respectively, but this number was lower for growth rate i.e., 141. However, the number of crosses with positive and negative cytoplasmic effects was also almost equal for all the four characters studied (Fig. 2).

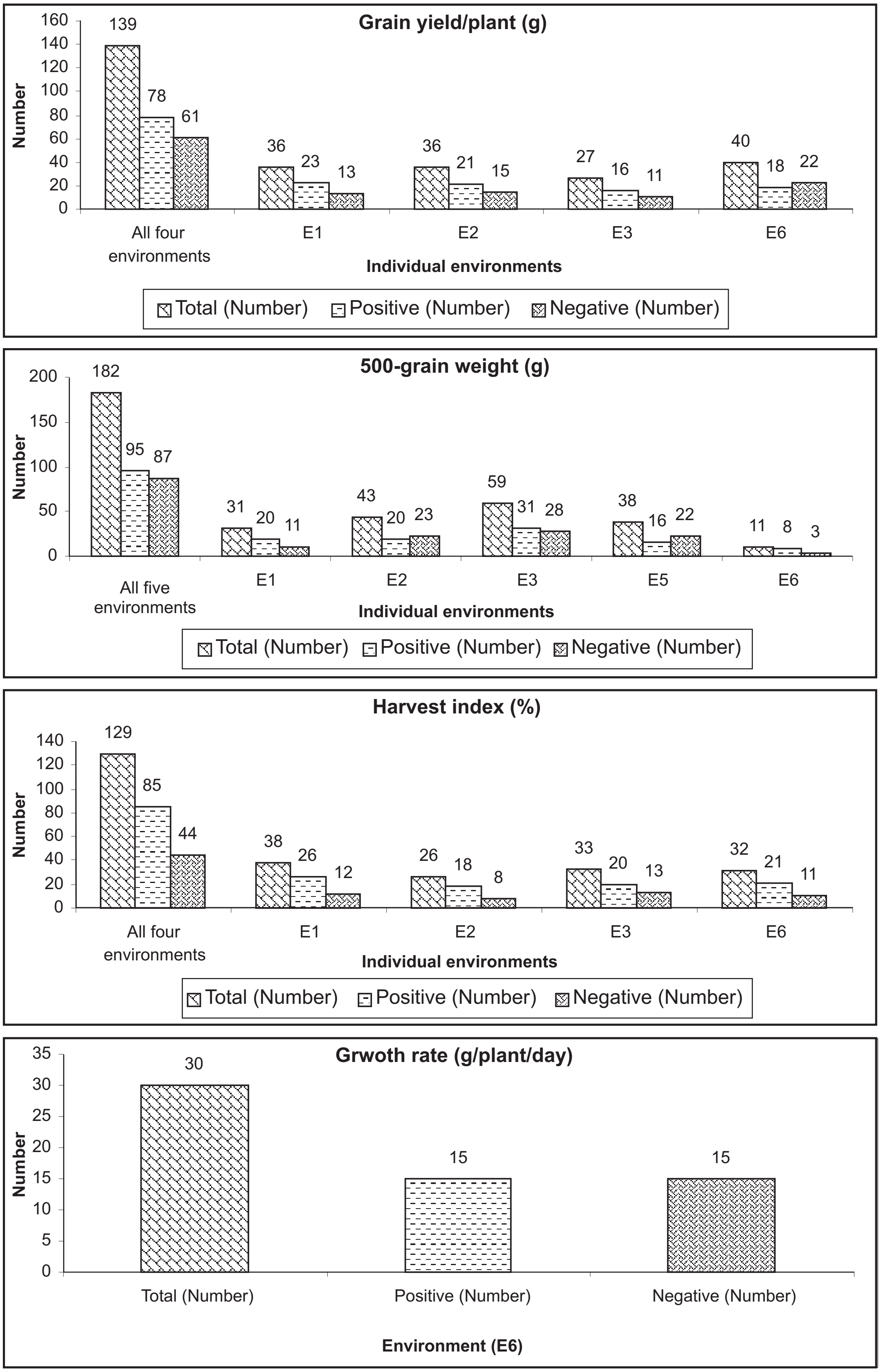

Fig. 1. **Bar diagram showing number of significant cytoplasmic effects (total, positive and negative) for four characters in different environments**

Table 4. Array means of 81A iso-hybrids for four quantitative characters in six environments

	2000						2001						Overall mean	
	E_1		E_2		E_3		E_4		E_5		E_6			
	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR
Grain yield/plant (g)														
Array mean (A/B x R)														
$81A_1$ & $81B_3$	32.4	34.1	29.8	28.7	25.6	24.8	31.9	33.9	29.2	27.7	28.9	27.5	29.6	29.4
$81A_4$ & $81B_4$	37.0	35.1	29.5	29.4	25.6	26.7	33.2	33.6	24.9	24.7	30.2	25.6	30.1	29.2
$81A_5$ & $81B_5$	38.8	33.7	29.6	28.7	26.0	27.2	35.0	32.8	27.7	27.2	28.8	29.1	31.0	29.8
CD at 5%		1.35		1.56		1.34		1.64		1.42		1.54		0.61
500-grain weight (g)														
Array mean (A/B x R)														
$81A_1$ & $81B_1$	4.24	4.25	3.91	3.88	4.47	4.23	4.15	4.12	3.56	3.86	4.05	4.01	4.06	4.06
81 A_4 & 81 B_4	4.22	4.15	3.83	3.91	4.38	4.55	4.24	4.34	3.75	3.85	4.36	4.22	4.13	4.17
$81A_5$ & $81B_5$	4.16	4.07	3.83	3.91	4.37	4.23	4.03	4.07	3.61	3.57	4.37	3.94	4.06	3.96
CD at 5%		0.11		0.10		0.06		0.10		0.11		0.20		0.05
Harvest index (%)														
Array mean (A/B x R)														
$81A_1$ & $81B_3$	29.4	29.2	28.2	27.6	29.4	28.1	29.2	30.1	29.4	29.0	29.2	27.1	29.1	28.5
81 A_4 & 81 B_4	30.1	29.3	27.4	27.4	28.3	27.7	29.5	28.8	29.1	28.3	30.7	28.3	29.2	28.3
$81A_5$ & $8IB_5$	31.3	29.3	27.8	27.1	29.2	27.8	30.4	29.3	29.8	30.9	29.7	30.0	29.7	29.1
CD at 5%		0.57		0.98		0.85		0.80		0.78		0.86		0.33
Growth rate (g/plant/day)														
Array mean (A/B x R)														
$81A_1$ & $81B_3$	1.28	1.33	0.88	0.89	1.09	1.11	1.13	1.15	0.82	0.79	1.16	1.19	1.06	1.08
81 A_4 & 81 B_4	1.42	1.35	0.93	0.94	1.15	1.21	1.14	1.18	0.70	0.71	1.12	1.06	1.08	1.07
$81A_5$ & $8IB_5$	1.36	1.33	0.90	0.90	1.10	1.22	1.14	1.16	0.77	0.70	1.12	1.09	1.07	1.07
CD at 5%		0.05		0.05		0.06		0.05		0.04		0.06		0.03

El & E4 = unratoon early sown crop, E2 & E5 ratoon crop, E3 & E6 unratoon late sown crop

None of the hybrids exhibited significant positive or significant negative specific combining ability effects for all the characters across the environments. However, hybrids $81A_1$ x 77/273 vs. $81B_1$ x 77/273, $313A_2$ x Raj 42 vs. $313B_2$ x Raj 42 and $81A_5$ x H90/4-5 vs. $81B_5$ x H90/4-5 exhibited significant positive effects in three to five environments for grain yield and 500-grain weight with sterile (A) cytoplasm *vis-a-vis* fertile (B) cytoplasm. This trend was also evident for other characters studied.

The cytoplasmic effects have bearing in the improvement of important traits like grain yield. Positive cytoplasmic effects for grain yield and component characters imply that the sterile cytoplasm adds to the performance. Positive influence of A_1 MS cytoplasm on grain yield have already been reported [12, 14]. The differential performance of cytoplasmic lines (A & B) may be attributed to the interaction between cytoplasm and nuclear genes [24, 25] therefore the performance of the male parent has also to be carefully accounted for [22, 23]. The negative cytoplasmic effect, however, could be effectively overcome by elite restorer lines via interaction of nuclear gene with female cytoplasm [26]. Our studies have revealed that 23 A_1 ($81A_1$ = 14, $8A_1$ = 9) cytoplasm based hybrids performed better for grain yield over four environments. However, 13 A_4 cytoplasm hybrids influenced grain yield in positive direction in all the four environments. Almost equal proportion of 81 A_1 and $81A_4$ cytoplasm hybrids and cytoplasmic-environment interactions *vis-a-vis* their positive effects on grain yield and its attributes can be exploited through

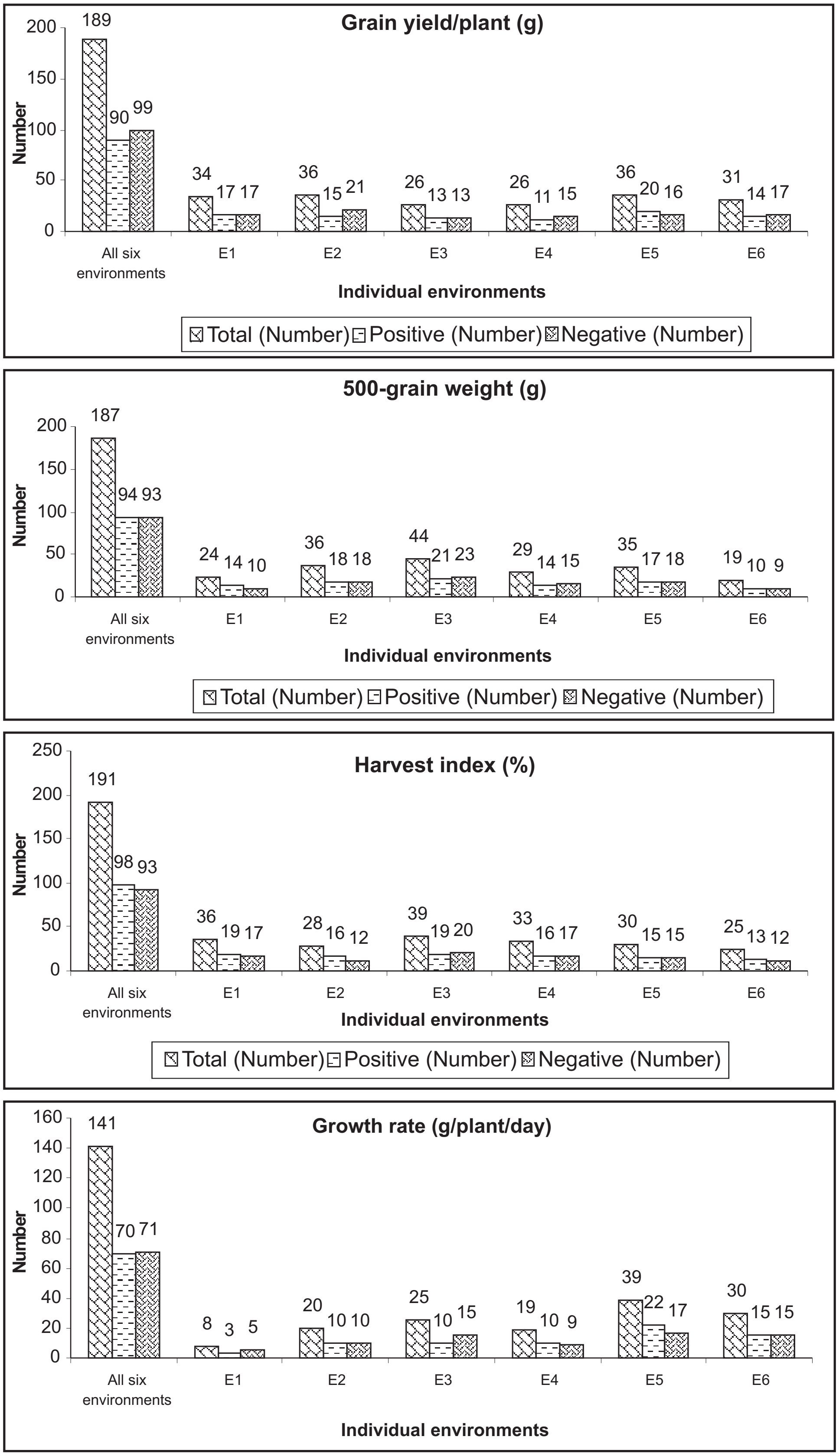

Fig. 2. Bar diagram depecting effect of cytoplasm on number of specific combining ability effects (total, positive and negative) for four characters in different environments

Table 5. Effect of cytoplasm on general combining ability of A/B lines and specific combining ability of some of their selected crosses for four quantitative traits

Genotypes	Grain Yield/Plant (g)						500-grain weight (g)					
	2000			2001			2000			2001		
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
81 A_1 vs. 81 B_1	-1.68*	1.11	0.80	-2. 01	1.41*	1.44	-0.01	0.03	0.24*	0.02	-0.31*	0.04
HMS8A_1 vs. 8B_1	-0.08	-1.78*	0.87	-3.04*	-0.12	-4.28*	0.09	0.01	0.31*	-0.02	0.05	0.03
Pb313A_2 vs. 313B_2	3.95*	0.56	3.00*	1.17	-0.03	-8.71	-0.05	-0.23*	-0.09*	0.02	-0.38*	-0.05
Pb402A_3 vs. 402B_3	1.14	3.78*	2.66*	-1.21	0.56	0.09	0.10	0.09	0.03	0.09	-0.07	-0.02
81 A_4 vs. 81 B_4	1.95*	0.06	-1.07	-0.39	0.25	4.64*	0.07	-0.08	-0. 17*	-0. 10*	-0.10*	0.14
81 A_5 vs. 81 B_5	5.13*	0.85	-1.13	2.17*	0.44	-0.32	0.09	-0.08	0.13*	-0.04	0.05	0.43
S.E.(d)	0.72	0.83	0.78	0.88	0.72	0.80	0.06	0.05	0.03	0.05	0.05	0.06
CD at 5%	1.41	1.63	1.53	1.72	1.41	1.57	0.12	0.10	0.06	0.10	0.10	0.12
F_1 hybrids												
81 A_1 x 77/273 vs. 81 B_1 x 77/273	10.68*	-9.82*	8.29*	9.91	9.50*	- 15.84*	0.53*	0.00	0.13	0.53*	0.69*	0.56*
81 A_1 x Raj. 42 vs. 8 B_1 x Raj.42	9.18*	-10.01*	7.60*	17.81	0.29	2.26	0.08	-0.09	-0.60*	0.07	-0.27	-0.39*
8 A_1 x Raj. 42 vs. 8 B_1 x Raj.42	14.48*	0.28	10.83*	1.54	6.63*	11.27*	0.54*	-0.60*	1-02*	1.02*	-0.05	0.16
313 A_2 x 77/180 vs. 313 B_2 x 77/180	1.75	14.54*	15.09*	1.04	6.62*	0.61	-0.18	0.55*	0.28*	-0.22	0.10	0.07
313 A_2 x Raj.42 vs. 313 B_2 x Raj. 42	7.35*	9.24*	-7.80*	14.33*	5.22*	4.11	0.46*	-0.72*	-0.04	0.45*	-1.03*	0.65*
402 A_3 x 77/273 vs. 402 B_3 x 77/273	9.86*	-1.38	10.74*	16.11*	-12.67*	-0.59	-0.30	0.74*	0.17	-0.33*	0.40*	-0. 91*
81 A_4 x G73-107 vs. 81 B_4 x G73-107	4.05	8.94*	2.77	4.30	8.75*	-5.94*	0.47*	1.05*	0.29*	0.31	1.51*	0.55*
81 A_4 x Raj. 42 vs. 81 B_4 x Raj. 42	5.45*	3.44	2.87	5.89	5.45*	6.56*	-0.04	0.17	0.14	-0.15	0.51*	-0.50*
81 A_5 x H90/4-5 vs. 81 B_5 x H90/4-5	0.76	16.75*	6.24*	0.83	13.96*	1.22	0.11	0.05	-0.63*	0.26	-0.04	-0.63*
81 A_5 x 77/180 vs. 81 B_5 x 77/180	7.36*	-3.65	0.44	9.13*	10.05*	-7.77*	0.03	0.92*	0.04	0.28	0.81*	0.37
S.E.(d)	2.50	2.89	2.69	3.05	2.51	2.78	0.22	0.17	0.10	0.17	0.17	0.20
CD at 5%	4.90	5.66	5.27	5.98	4.92	5.45	0.43	0.33	0.20	0.33	0.33	0.39
	Harvest index (%)						Growth rate (g/plant/day)					
81 A_1 vs. 81 B_1	0.21	0.63	1.26*	-0.91	0.38	2.03*	-0.04	-0.01	-0.02	-0.02	0.02	0.03
HMS-8A_1 vs. 8B_1	0.42	-0.69	-0.21	-0.18	-0.97*	-0.44	-0.02	-0.01	0.03	-0.06*	0.04	-0. 15*
Pb-313A_2vs. 313B_2	1.53*	0.78	1.47*	0.22	1.74*	-3.09*	0.06	-0.02	0.03	0.04	-0.05	-0.22*
Pb-402A3 vs. 402B_3	0.09	3.48*	-0.42	-0.88*	1.87*	0.56	-0.09	-0.02	0.19*	0.00	-0.04	-0.02
81 A_4 vs. 81 B_4	0.73*	0.06	0.51	0.77*	0.77	2.37*	0.07	0.00	-0.05	-0.04	-0.01	0.06*
81 A_5 vs. 81 B_5	2.03*	0.75	1.38*	1.12*	-1. 11	-0.29	0.04	-0.01	-0. 12*	-0.01	0.07*	0.03
S.E.(d)	0.30	0.48	0.36	0.38	0.36	0.43	0.06	0.02	0.03	0.03	0.02	0.03
CD at 5%	0.59	0.94	0.71	0.74	0.70	0.84	0.12	0.04	0.06	0.06	0.04	0.06
F_1 hybrids												
81 A_1 x 77/273 vs. 81 B_1x 77/273	-0.94	-9.29*	3.06*	0.91	4.83*	-9-03*	0-51*	0.01	0.27*	0.27*	0.07	-0.15
81 A_1 x Raj. 42 vs. 81 B_1 x Raj. 42	4.24*	0.55	2.01	6.22*	5.51*	-0.61	0.12	-0.29*	0.24*	0.42*	-0.20*	0.22*
8 A_1 x Raj. 42 vs. 8 B_1 x Raj. 42	8.21*	-2.94	10.18*	-1.32	-0.01	4.24*	0.06	0.08	-0.17	0.16	0.23*	0.28*
313 A_2 x 77/180 vs. 313 B_2x77/180	2.84*	6.35*	3.00*	4.19*	4.07*	0.95	-0.14	0.14	0.46*	-0.26*	0.00	-0.06
313 A_2 x Raj. 42 vs. 313 B_2 x Raj. 42	5.00*	7.66*	1.37	8.73*	5.82*	2.49	-0.03	-0.05	-0.38*	0.09	-0.01	0.00
402 A_3 x 77/273 vs. 402 B_3 x 77/273	2.45*	-1.56	1.35	5.73*	-0.78	1.22	0.46*	0.04	0.54*	0.44*	-0.35*	-0.16
81 A_4 x G73-107 vs. 81 B_4 x G73-107	2.38*	-1.82	-4.61	-0.13	1.76	-3.60*	0.05	0.31*	0.49*	0.13	0.16*	-0.04
81 A_4 x Raj. 42 vs. 81 B_4 x Raj. 42	0.66	2.11	-0.56	3.67*	-1.55	6.23*	0.16	0.02	0.13	-0.02	0.18*	0.00
81 A_5 x H90/4-5 vs. 81 B_5 x H90/4-5	2.62*	2.23	7.46*	-2.99*	1.97	-0.75	0.19	0.37*	-0.17	0.15	0.31*	0.05
81 A_5 x 77/180 vs. 81 B_5 x 77/180	0.61	0.69	-0.34	2.57	3.97*	-5.61	0.25	-0.14	0.02	0.18	0.14*	0.05
S.E.(d)	1.03	1.66	1.23	1.32	1.23	1.47	0.20	0.08	0.10	0.10	0.06	0.10
CD at 5%	2.02	3.25	2.41	2.59	2.41	2.88	0.39	0.16	0.20	0.20	0.12	0.20

* Significant at 5% level; E1 8s E4 = unratoon early sown crop, E2 & E5 = ratoon crop, E3 & E6 unratoon late sown crop

breeding of both systems specific hybrids for specific environmental niches.

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