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EFFECT OF CYTOPLASM ON COMBINING ABILITY AND DRY FODDER YIELD CONTRIBUTING TRAITS IN PEARL MILLET [*PENNISETUM GLAUCUM* (L.) R. BR.]

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SUMMARY

The effect of cytoplasm on dry fodder yield and combining ability for dry fodder 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), $81A_4$ and $81A_5$] 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 (El, E2 and E3) and (E4, E5 and E6) during two years. The data were reported for dry fodder yield (g/plant) and major dry fodder yield contributing characters–plant height (cm), total tillers at maturity and number of leaves per main tiller. Analysis of variance revealed significant differences among genotypes, parents, lines (A, B), testers and hybrids (A x R, B x R). The differences due to A vs. B were non- significant except for dry fodder yield (g/plant) and number of leaves per main tiller; and A x R vs. B x R crosses were significant except for number of leaves per main tiller. Cytoplasmic effects were estimated by comparing A x R and B x R hybrids combination. The results indicated that a few number of cytoplasmic effects was significant. Both positive and negative cytoplasmic effects were observed for three characters viz., dry fodder yield (g/plant), plant height (cm) and total tillers at maturity. The (A x R vs. B x R) x E component of variance exhibited significance for all the characters except for number of leaves per main tiller. The effects were modified by environment and were more pronounced for dry fodder yield, plant height and total tillers and negative cytoplasmic effects exceeded than the positive ones. The negative cytoplasmic effects were preponderant for dry fodder yield and significant only in one environment which was 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. The effect of cytoplasm on general combining ability both positive and negative was highest for lines HMS $8A_1$, $81A_1$, Pb402A_3 and $81A_5$. Array mean performance of 81A cytoplasmic iso-hybrids indicated that all the three cytoplasms had same potential; therefore, any of these cytoplasms can be used in hybrid breeding.

Key words : Pearl millet, cytoplasmic effects, combining ability

Pearl millet is an important food, feed and fodder (both stover and green forage)–dual purpose crop. It is generally cultivated under most trying conditions of heat and drought in arid and semi-arid tropics and largely a single crop is taken under rainfed conditions. In Haryana, it was cultivated in an area of 4.11 lakh hectares with a production of 7.85 lakh tonnes and an average productivity of 1910 kg/ha as against area of 7.29 m ha with grain production of 8.74 m tonnes and productivity of 1198 kg/ha in India (Anonymous, 2014).

The occurrence of CMS in some of the crop plants is best utilized as an important genetic tool in hybrid breeding. Burton (1958) 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-1 by Athwal (1965) using Tift 23A, male sterile line and BIL-3B, restorer. However, successful utilization of CMS in hybrid breeding also depends on the availability of specific nuclear restorer genes which down regulate the male sterilizing factors (Touzet and Budar, 2004). Similarly, extensive use of a single CMS source (cytoplasmic monoculture) not only narrows the cytoplasmic diversity but also potentially exposes the hybrids to vulnerability of disease and insect-pest epidemics

(Scheifele *et al.*, 1970; Chatel *et al.*, 1996; Kumar and Sagar, 2010). Delorme *et al.* (1997) suggested, however, there was need to diversify the cytoplasmic bases of hybrids to reduce the potential hazards of vulnerability and also provide opportunities for greater genetic diversity of male sterile lines and their hybrids. Therefore, different sources of MS cytoplasm such as A^2, A^3 (Burton and Athwal, 1967), Maiwa (Aken'ova, 1982), A^4 (Hanna, 1989) and A^5 (Rai, 1995), have been discovered. In a hybrid breeding programme based on cytoplasmic male sterility, plant breeders are always concerned with the effects of sterility inducing cytoplasm on agronomic traits. The CMS lines have been used in development of commercial and test hybrids, although reciprocal cross effects were observed for a number of characters in pearl millet (Virk, 1988). Identification of cytoplasmic influence on dry matter yield and other agronomic characters could have a major impact on improving plant performance worldwide since the cytoplasm is contributed by the seed parent to its progeny. Though, Hanna (1982) did not observe significant differences for dry matter yield among four different cytoplasms but Hanna (1997) did observe influence of cytoplasm on dry matter yields, and advocated for further studies to distinguish between cytoplasmic and cytoplasmic nuclear effects. The availability of an identical genome in different cytoplasms provides a unique opportunity for the critical analysis of the role of cytoplasm.

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 dry fodder 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 ($MS81A_1$ and $HMS\ 8A_1$) 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 12 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 with 12 restorer lines in a line × tester mating design at ICRISAT, Hyderabad, during off season. The 144 hybrids thus produced and their parents were grown separately in contiguous blocks in randomized block design with two replications in six artificially created environments viz. (E1, E2, E3 and E4, E5, E6) during two years. The environment crop represents early sown non-cut crop (E1, E4), ratoon crop (E2, E5) and late sown non-ratooned (E3, E6) at Research Farm, Bajra Section, Department of Plant Breeding, CCSHAU, Hisar during **kharif** season. The ratoon crop (E2, E5) was cut at a height of approximately 12 cm after 40 days of sowing and left to regenerate. The plot size was 2R × 2.5 m × 0.45 m with 10 cm intra-row spacing. All the recommended agronomic practices were followed to raise a good crop.

Data were recorded on five competitive plants in each plot in each replication. The observations were recorded on dry fodder yield (g/plant), plant height (cm), total tillers at maturity and number of leaves per main tiller 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 (1977). The combining ability analysis was performed following Kempthorne (1957).

RESULTS AND DISCUSSION

The analysis of variance of the data performed for the four characters studied in six environments during two years is presented in Table 1. The mean squares due to genotypes were highly significant for all the characters studied. Thus, partitioning of the genotypes sum of squares into parents, hybrids and parents *vs.* hybrids was appropriate. The significant sum of squares due to parents and hybrids also allowed partitioning of these components into lines (A lines, B lines, A vs. B lines), testers, lines vs. testers and A x R hybrids, B x R hybrids, A x R vs. B x R hybrids, respectively. The differences due to A x R vs. B x R crosses were significant in individual environment for dry fodder yield in E6, plant height in E2 and E4, and for total tillers in E1 and E4. This indicated that the cytoplasmic effects were important for expression of these characters. The combined analysis of variance presented in Table 2 revealed significant differences between environments,

TABLE 1
Combined analysis of variance for some quantitative traits in different environments during two years

Source of variation	d. f.	Mean squares			
		Dry fodder yield (g/plant)	Plant height (cm)	Total tillers at maturity	No. of leaves/main tiller
Rep. in environments	6	160.64	131.37	3.08	1.14
Environments (E)	5	16309.04**	83012.90**	28.21**	436.49**
Year	1	8774.6**	62366.75**	15.49**	96.91**
Date	2	25091.01**	172391.37**	16.17**	973.31**
Year × Date	2	11294.29**	3957.52**	46.62**	69.44**
Genotypes (G)	167	1970.18**	9865.66**	1.74**	4.99**
Parents (P)	23	293.11**	6625.60**	3.26**	5.55**
Lines	11	90.19**	3343.23**	3.01**	1.25**
A lines	5	108.06**	3360.12**	2.96**	1.06**
B lines	5	31.78	3992.73**	3.62**	1.52**
A vs. B	1	292.98**	11.28	0.2	0.81*
Testers	11	504.97**	4172.40**	3.80**	8.51**
Lines vs. Testers	1	194.7*	69716.80**	0.02	20.37**
Hybrids (H)	143	580.74**	1886.28**	1.47**	2.45**
P vs. H	1	239232.98**	1225437.50**	5.73**	355.41**
A x R hybrids	71	621.29**	1966.88**	1.55**	2.29**
B x R hybrids	71	544.63**	1831.64**	1.27**	2.65**
A x R vs. B x R	1	265.63**	43.61	10.19**	0.07
G×E	835	243.60**	330.63**	1.13**	0.85**
P×E	115	116.64**	261.87**	1.30**	1.38**
H×E	715	249.68**	306.19**	1.10**	0.66**
(P vs. H) × E	5	2295.23**	5406.18**	0.97*	15.37**
A x R × E	355	244.92**	292.69**	.089**	0.58**
B x R × E	355	254.90**	321.30**	1.30**	0.74**
(A x R vs. B x R) × E	5	216.95**	191.84**	2.25**	0.15
Error	1002	37.67	60.28	0.37	0.13

*,**Significant at P=0.05 and P=0.01 levels, respectively.

genotypes i. e. parents, lines, testers, hybrids (A x R, B x R) and also their interaction with environments for the characters studied. The cytoplasmic effects for 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 except number of leaves per main tiller (Table 1). Significant cytoplasmic effects total, positive and negative for the three traits are presented in Fig. 1 and a few selected crosses in Table 3. A few numbers of significant cytoplasmic effects were observed for three characters i. e. of total 432 paired comparisons in six environments, the number of crosses 30 (E6), 27 (E2 & E4) and 44 (E1, E4 & E6) exhibited significance for dry fodder yield, plant height and total tillers at maturity, respectively.

Dry Fodder Yield at Maturity

The significant cytoplasmic effects for dry fodder yield were recorded in E6 only. Of the 72 possible comparisons, 30 showed statistically significant cytoplasmic effects. Nine of the 30 paired significant crosses expressed positive significant cytoplasmic effects and 21 negative significant cytoplasmic effects (Fig. 1). Maximum number of significant positive and significant negative cytoplasmic effects were recorded in $81A^5/B^5$ and 313 A_2/B_2 lines hybrids, respectively. Least number of significant cytoplasmic effects was noted in $81A^4/B^4$ lines crosses. The hybrid combinations viz., HMS 8A_1 x R21 vs. HMS 8B_1 x R21, Pb. 402 A_3 x R19 vs. Pb 402B_3 x R19, 81 A4 x R22 vs. 81 B_4 x R22 81 A_5 x R15 vs. 81 A_5 x R15 exhibited positive significant cytoplasmic effects (Table 3). The significant positive effects were preponderant in hybrids of 81A_4/B_4 (1, 0), 81A_5/B_5 (4, 3) but in case of 81A_1/81B_1 (0, 3), Pb 313A_3/Pb.313 B_3 (1, 7) the number of significant negative effects exceeds the positive one.

Plant Height at Maturity

Twenty-seven of 144 possible comparisons pronounced significant cytoplasmic effects in E2 and

TABLE 2
Analysis of variance for dry fodder yield contributing characters in different environments during two years

Source of variation	d. f.	Mean squares											
		E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
		Dry fodder yield (g/plant)						**Plant height at maturity (cm)**					
Replication	1	116	89.07	26.3	5.87	662.77	62.92	262.53	4.03	82.41	78.11	357.95	3.2
Genotype	167	573.69**	478.21**	513.70**	679.95**	466.16**	476.49**	2344.08**	1686.55**	1799.63**	2462.30**	1324.06**	1902.16**
Parents	23	124.83**	181.29**	73.27**	140.40**	253.14**	103.38**	1709.36**	1415.25**	796.31**	1545.86**	1278.06**	1190.11**
Lines	11	60.83*	28.43	24.84	66.22	120.84**	75.2	571.98**	456.28**	717.01**	716.27**	688.25**	705.94**
A lines	5	99.59**	37.13	47.05	75.85	31.1	75.44	672.10**	295.92**	660.04**	803.39**	489.88**	864.07**
B lines	5	32.16	24.75	7.3	43.13	196.89**	35.86	586.24**	678.70**	855.46**	754.77**	998.97**	688.73**
A vs. B	1	10.4	3.38	1.5	133.48	189.28*	270.68**	0.11	146.03	309.60**	88.17	126.5	1.31
Testers	11	194.23**	326.19**	78.66*	222.50**	403.53**	127.46**	1515.40**	1254.12**	313.08**	996.85**	1322.33**	808.28**
Lines vs. Testers	1	65.33	268.85*	546.75**	53.34	54.19	148.4	16354.08**	13736.33**	6984.19**	16710.40**	7279.15**	10716.16**
Hybrids	143	283.26**	244.59**	287.44**	295.95**	403.73**	314.15**	576.27**	505.26**	431.52**	640.09**	570.02**	694.05**
P vs. H	1	52430.04**	40714.27**	42997.79**	68001.64**	14291.77**	32273.60**	269739.29**	176850.16**	22056.05**	284116.53**	110208.28**	191038.08**
A x R hybrids	71	351.50**	240.25**	270.40**	289.05**	370.07**	324.60**	619.16**	487.89**	510.04**	617.73**	545.04**	650.48**
B x R hybrids	71	218.48**	251.39**	308.52**	305.10**	442.63**	293.10**	541.45**	524.44**	359.06**	669.33**	601.78**	742.06**
A x R vs. B x R	1	37.12	70.61	1.28	136.4	32.33	1072.62**	3.25	377.21*	0.74	151.96	89.67	379.96*
Error	167	31.65	46.06	37.26	38.11	30.99	41.94	72.38	91.74	35.1	50.59	37.44	74.39
		Total tillers at maturity						**Number of leaves/main tiller**					
Replication	1	0.8	0.76	0.05	2.4	2.71	2.82	0.007	0.121	1.685	0.651	0.1	4.297
Genotype	167	1.06**	1.76**	0.71**	1.43**	2.25**	1.69**	1.834**	1.496**	1.694**	1.792**	1.018**	1.384**
Parents	23	1.17**	2.54**	0.89**	3.42*	4.46**	1.50**	2.994*	1.912**	2.036**	2.414**	1.468**	1.639**
Lines	11	1.14**	1.88**	0.16	3.83**	4.47**	0.17	0.965**	0.401**	0.721**	0.845**	0.737**	0.684**
A lines	5	0.83**	1.65**	19	3.38**	3.32**	0.23	0.646**	0.510**	0.317	0.224	0.312	0.883**
B lines	5	1.62**	2.48**	0.12	4.78**	6.33*	0.13	1.381**	0.374*	0.837**	1.427**	1.085**	0.622**
A vs. B	1	0.28	0.01	0.24	1.31	0.88	0.03	0.481*	0.0001	2.16**	1.041**	1.126*	0.006
T esters	11	1.28**	3.40**	1.41**	1.39**	2.53**	1.19*	5.265**	1.728**	0.83**	4.201**	2.129**	1.759**
Lines vs. Testers	1	0.19	0.33	3.20**	21.33**	25.52**	9.51**	0.333	20.54**	29.767**	0.02	2.253**	0.83**
Hybrids	143	1.05**	1.52**	0.69**	1.12**	1.76**	1.60**	1.064**	0.94**	0.719**	1.168**	0.952**	0.896**
P vs. H	1	0.02	18.52**	0.37	0.2	21.79**	18.55*	85.346**	71.51**	133.302**	76.611**	0.008	65.433**
A x R hybrids	71	0.73**	1.54**	0.68**	1.01**	1.48**	0.88**	1.008**	0.875**	0.610**	1.012**	0.798**	0.882**
B x R hybrids	71	1.24**	1.53**	0.70**	1.18**	2.06**	2.24**	1.133**	1.018**	0.838**	1.336**	1.116**	0.922**
A x R vs. B x R	1	9.32**	0.32	0.35	4.40**	0.2	6.54**	0.08	0.011	0.005	0.361	0.256	0.093
Error	167	0.19	0.22	0.34	0.44	0.55	0.52	0.091	0.156	0.149	0.145	0.164	0.085

E1 & E4–Unratoon early sown crop, E2 & E5–Ratoon crop, and E3 & E6–Unratoon late sown crop.
*,**Significant at P=0.05 and P=0.01 levels, respectively.

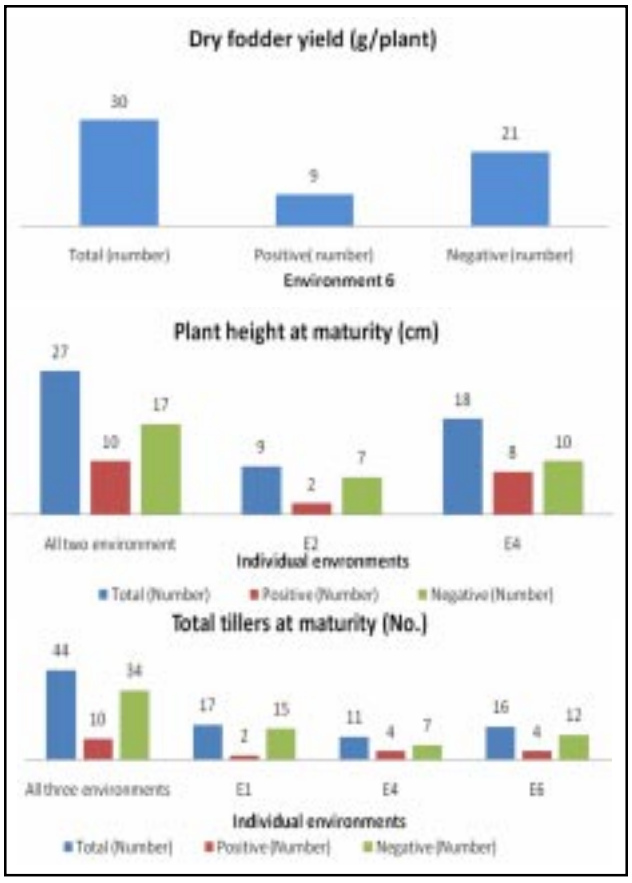

Fig. 1. Bar diagram showing number of significant cytoplasmic effects (total, positive and negative) for three characters in different environments.

E6 (Fig. 1). The number of paired crosses exhibiting significant positive and significant negative cytoplasmic effects was 10 and 17, respectively. The number of significant positive cytoplasmic effects was preponderant in 8A/B and 313A/B lines hybrids. The highest number of significant cytoplasmic negative effects was recorded in crosses of $402A_3/B_3$ followed by $81A^4/B^4$ and 81A/B.

Hybrid cross combinations HMS $8A_1$ x R21 vs. HMS $8B_1$ x R21, Pb $313A_2$ x R21 vs. Pb 313 B_2 x R21 and $81A_5$ x R21 vs. $81B_2$ x R21 exhibited positive significant effects in E6 and non-significant in E2 (Table 3).

Total Tillers at Maturity

Forty-four crosses expressed significant cytoplasmic effects out of 216 possible cases in the three environments viz., E1 (17), E4 (11) and E6 (16) (Fig. 1). Ten of 44 crosses characterized significant positive effects and 34 significant negative cytoplasmic effects. The crosses $81A_4$ x R22 vs. $81B_4$ x R22, $81A_4$ x R21 vs. $81B_4$ x R21 and $81A_4$ x R18 vs. $81B^4$ x R18 exhibited significant positive cytoplasmic effects in two of the three environments. However, comparison of hybrid $81A_4$ x R22 vs. $81B_4$ x R22 exhibited significant negative cytoplasmic effects in E4 environment. The highest magnitude of significant positive cytoplasmic effects was noted in crosses 313A x R18 vs. 313B x R18 in E6 followed by $81A^4$ x R22 vs. $81B^4$ x R22 in E6.

TABLE 3

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

Crosses	Dry fodder yield (g/plant)	Plant height at maturity (cm)		Total tillers		
	E6	E2	E6	E1	E4	E6
$81A_1$ x R20 vs. $81B_1$ x R20	-22.6*	-8.5	1.7	-0.3	-0.1	0.1
$81A_1$ x R21 vs. $81B_1$ x R21	-13.2*	5.8	-36.6*	0.2	-1.2	0.0
HMS $8A_1$ x R20 vs. HMS $8B_1$ x R20	-30.2*	3.7	-13.2	-0.2	0.4	-0.3
HMS $8A_1$ x R21 vs.HMS $8B_1$ x R21	22.7*	5.8	25.7*	0.8	-1.0	-0.3
Pb. $313A_2$ x R20 vs. Pb. $313B_2$ x R20	-12.4	9.0	-7.7	0.4	0.5	-1.2
Pb. $313A_2$ x R21 vs. Pb. $313B_2$ x R21	-13.7*	13.6	23.9*	0.4	-0.6	-1.2
Pb. $402A_3$ x R19 vs. Pb. $402B_3$ x R19	13.6*	-2.7	-19.0*	-0.5	0.4	1.0
Pb. $402A_3$ x R21 vs. Pb. $402B_3$ x R21	-24.8*	12.4	3.2	-1.1*	0.1	-0.7
$81A_4$ x R22 vs. $81B_4$ x R22	29.0*	-4.2	-10.6	0.6	-0.8	2.01*
$81A_4$ x R21 vs. $81B_4$ x R21	2.4	4.8	-12.5	0.6	-2.7*	2.2*
81A x /R15 vs. $81B_5$ x R15	24.0*	-13.2	-0.5	-0.6	1.2	-1.5*
$81A_5$ x R21vs. $81B_5$ x R21	-6.9	15.4	18.4*	.02	1.1	0.0
C. D. (P=0.05)	12.7	18.8	17.0	0.9	1.31	1.4

*Significant at P=0.05 level. E1 & E4–Unratoon early sown crop, E2 & E5–Ratoon crop and E3 & E6–Unratoon late sown crop.

The number of significant positive and negative effects was equal in Pb. $313A_2/B_2$ crosses and in other lines crosses significant negative effects were preponderant.

A number of paired crosses showed significant positive cytoplasmic effects in one environment and significant negative in another e. g. cross $81A_4$ x R21vs. $81B_4$ x R21 (Table 3).This indicated that cytoplasmic effects were results of interaction between the cytoplasm and nuclear-genome and were modified by environment are akin to Yadav (1994), Kumar and Sagar (2010) in pearl millet and Morgan and Rooney (2003) in sorghum.

In some studies the cytoplasmic male sterile based hybrids outyielded their fertile counterparts (Rogers and Edwardson, 1952; Rogers, 1954) but in other studies this was not found (Jones and Mangelsdorf, 1951; Josephson and Kincer, 1962). Cytoplasmic effects were also recorded for agronomic characters–days to flowering, plant height, grain yield (Young and Virmani, 1990), cold tolerance (Ratho and Pradhan, 1992) and yield, width of flag leaf and low temperature tolerance (Tao *et al.*, 2004) in rice. Significant cytoplasm-nucleus interactions on yield, plant height and low temperature tolerance were also observed. Virk and Brar (1993) also observed the significant differences among iso-nuclear cytoplasmic lines in mean value for traits e. g. plant height, leaf length and peduncle length, but differences for combining ability were more pronounced.

The inconsistency in number of significant cytoplasmic effects under differing environment recorded in the present study probably was modified by interaction with environments and is supported by the observation of Yadav (1994). However, negative cytoplasmic effect could be effectively overcome by crossing elite restorer lines with the female cytoplasm i. e. utilizing the interaction of nuclear genes with cytoplasm. The higher/equally good number of positive cytoplasmic effects of male sterile lines (402A, $81A^5$) other than A_1 system for dry fodder yield and Pb. 313 A_2 for plant height and total tillers, the major characters of fodder productivity are encouraging and suggest that these lines should be extensively used in pearl millet hybrid development. Already one hybrid other than A^1 system, GHB 316 based on A^3 (403A) and another HHB 216 based on A_4 (HMS 37A) have been released for general cultivation in Gujarat (1997) and Haryana (2010), respectively.

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) hybrids. The iso-hybrids $81A_1$ vs. $81B_1$ in E4 and E5, $81A_4$ vs. $81B_4$ in El and E6; $81A_5$ vs. $81B_5$ in El, E4, E5 and E6, $81A_1$vs. $81B_1$ in E5 performed better for dry fodder yield. None of the different system hybrids ($81A_1$, $81A_4$, $81A_5$) uniformly and significantly excelled between them except for the differential responses. However, a few of $81A_5$ hybrids performed significantly better than $81A_1$ in E1and E4, $81A_1$ better than $81A_4$ and $81A_5$ in E5 for dry fodder yield. For plant height performed better in E5 only and E4 and also on pooled basis. The hybrids of $81A_1$ significantly performed superior for total tillers and for number of leaves/main tiller and were better than $81A_4$ and 81_5 hybrids. As the hybrids of any one system were uniformly better for all the characters. 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 36 pairs of comparisons of 12 lines (six A, six B) in six environments, 10 for dry fodder yield, 15 for plant height, 14 for total tillers and 15 for number of leaves/main tiller depicted significant gca differences. Only one parent $Pb.402A_3/Pb.402B_4$ exhibited positive cytoplasmic effects on gca for dry fodder yield in E3. Similarly, parents $81A_1/81B_1$ and $8A_1/8B_1$ expressed significant positive cytoplasmic effects on gca effects in two or more environments for plant height and $Pb.313A_2/Pb.313A_2$ for total tillers. It showed that when either of the lines i. e. A or B was 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 $81A_1/81B_1$ and $8A_1/B_1$ and $81A_4/81B_4$ for dry fodder yield; $81A_1/81B_1$, $81A_4/81B_4$ and $81A_5/81B_5$ for plant height and $8A_1/81B_1$ and $81A_5/81B_5$ for total tillers and $81A_1/81B_1$ for number of leaves having significant negative values in two or more numbers of environments. Here it shows that A-lines performed better in hybrids. The effect of cytoplasm on sca of crosses was observed for all the four characters i. e. of total 432 paired comparison, the number of crosses 143,107, 72 and 72 exhibited significance for dry fodder yield, plant height, total tillers and number of leaves per main tiller, respectively. However, the number of crosses with positive and negative cytoplasmic effects was also

TABLE 4
Array means of 81A iso-hybrids for four quantitative characters in different environments

	E1		E2		E3		E4		E5		E6		Overall mean	
	A x R	B x R	A x R	B x R	A x R	B x R	A x R	B x R	A x R	B x R	A x R	B x R	A x R	B x R
Dry fodder yield/plant (g)														
Array mean (A/B x R)														
$81A_1$ & $81B_3$	77.31	82.45	74.75	75.43	61.5	63.08	72.39	67.67	70.07	67.67	70.19	73.48	71.77	73.38
$81A_4$ & $81B_4$	86.25	83.48	78.11	78.71	64.89	68.86	79.3	82.5	59.4	60	68.48	65	72.73	73.16
$81A_5$ & $1B_5$	84.78	83.41	76.3	77.28	63.04	70.08	79.96	79.36	65.62	59.93	68.03	67.43	72.96	72.64
C. D. (P=0.05)	3.16		3.82		3.45		3.47		3.13		3.65			
Plant height at maturity (cm)														
Array mean (A/B x R)														
$81A_1$ & $1B_1$	214	215.8	179.4	185.1	195.1	197.9	206.7	214.8	171.5	168.2	182.9	188.5	191.6	195.1
$81A_4$ &$81B_4$	209.5	215.7	184.1	185.8	197.5	194.8	212.2	212.7	170.8	174.6	179.3	186.1	192.3	194.9
$81A_5$ & $8IB_5$	219.3	214.7	184.6	183.7	196.2	201.8	217.3	211.2	171.4	170.5	185.5	188	195.7	195
C. D. (P=0.05)	4.78		5.23		3.27		3.89		3.03		4.75			
Total tillers														
Array mean (A/B x R)														
$81A_1$ & $81B_3$	3.47	4.08	3.9	3.68	2.98	3.05	3.56	3.99	4.08	7.07	4.36	4.31	3.78	3.86
$81A_4$ & $81B_4$	3.7	3.63	3.55	4.08	3.38	2.73	3.53	4.51	3.83	3.73	4.25	4.23	3.72	3.83
$81A_5$ & $8IB_5$	3.58	3.94	4.29	4.27	2.78	3.13	3.88	3.67	3.91	3.82	3.84	3.94	3.73	3.88
C. D. (P=0.05)		0.26		0.26		0.32		0.37		0.39		0.39		
Number of leaves														
Array mean (A/B x R)														
$81A_1$ & $81B_3$	9.14	9.62	6.95	6.81	8.84	9.03	9.43	9.63	6.65	6.44	7.68	7.88	8.13	8.25
$81A_4$ & $81B_4$	9.4	9.08	7.03	6.88	8.43	8.98	9.16	9.29	6.61	6.58	7.65	7.75	8.17	8.01
$81A_5$ & $8IB_5$	9.45	9.35	6.83	6.9	8.96	9.02	9.28	9.27	6.53	6.65	7.68	7.93	8.12	8.2
C. D. (P=0.05)		0.16		0.22		0.19		0.18		0.16		0.15		

E1 & E4–Unratoon early sown crop, E2 & E5–Ratoon crop, E3 & E6–Unratoon late sown crop.

almost equal for all the four characters studied (Fig. 2).

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, $8A_1$ x Raj 42 vs. $8B_1$ x Raj 42 and Pb. 313 A_2 x 77/273 vs. $313B_2$ x 77/273 exhibited significant positive effects in three to five environments for dry fodder yield and $8A_1$ x Raj 42 vs. $8B_1$ x Raj 42 exhibited significant positive effects for dry fodder yield (E2, E5 and E6), plant height (all six environments), total tillers at maturity (E5) and number of leaves/main tiller (E1 and E2) with sterile (A) cytoplasm vis-a-vis fertile (B) cytoplasm. Kumar and Sagar (2010) also reported that effect of cytoplasm was more or less equally pronounced on gca effects of parents and sca of crosses for grain yield/plant (g), harvest index (%), growth rate (g/plant/day) and 500-grain weight. However, cytoplasm had limited effect on gca effects of A-lines and on sca effects of iso-nuclear hybrids for days to 50 per cent flowering, plant height and grain yield in sorghum (Belum *et al*., 2007).

The cytoplasmic effects on specific combining ability (sca) for the four agronomic traits are presented in Table 5. The data indicated that there were both positive and negative significant effects of the male sterile cytoplasms under study on all the four characters studied. Also, there were differential effects of a cytoplasm on sca under different environmental conditions. This implies that the cytoplasmic effects on sca were greatly influenced by the interaction of cytoplasm with the nuclear genes rather than cytoplasm *per se* and the environmental factors can modulate the cytoplasmic-nuclear interaction. Therefore, it is important to evaluate the cytoplasmic effects in combination with different nuclear backgrounds in the process of selecting parental lines to be utilized in hybrid breeding.

In conclusion, the study indicated that, in addition to the widely used A_1 CMS, the A_4 and A_5 CMS sources offered potential alternatives to diversify the male sterile cytoplasm in dual purpose pearl millet crop.

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

Genotypes	Dry fodder yield/plant (g)						Plant height at maturity (cm)					
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
Lines	-5.14*	-0.67	-1.58	-1.35	2.4	-3.3	-1.68	-5.70*	-2.79	2.94	3.38*	-5.61*
81 A_1 vs. 81 B_1												
HMS 8A_1 vs. 8B_1	-1.79	-1.04	2.19	-6.11*	3.56*	-10.31*	8.75*	0.19	-8.06*	8.95*	10.15*	0.58
Pb. 313A_2 vs. 313B_2	-2.67	-0.61	1.99	2.29	-4.25*	-12.67*	4.29	3.9	5.97*	-3.25	0.17	-0.85
Pb. 402A_3 vs. 402B3	2.5	-2.05	9.22*	-0.47	-2.71	-0.89	-8.37	-11.43*	-1.81	-3.39	3.59*	-6.08*
81 A_4 vs. 81 B_4	2.37	-0.6	-3.97*	-3.2	-0.59	3.47	-6.19*	-1.61	2.69	0.96	-3.78*	-6.77*
81 A_5 vs. 81 B_5	3.04	-0.97	-7.05*	0.6	5.62*	0.6	0.02	0.94	-5.62*	3.62	0.85	-2.48
S. E(d)	1.69	1.99	1.84	1.89	1.6	1.9	2.55	2.8	1.73	3.22	1.62	2.54
C. D. (P=0.05)	3.31	3.9	3.61	3.7	3.14	3.72	5	5.49	3.39	6.31	3.18	4.98
F_1 hybrids												
81 A_1 x 77/273 vs. 81B_1 x 77/273	26.74*	2.68	12.49*	19.26*	6.2	-6.81	-3.42	-5.7	8.18	6.68	2.51	3.22
8 A_1 x Raj 42 vs. 8B_1 x Raj 42	1.03	13.54*	-12.29	8.5	21.94*	18.68*	30.25*	29.02*	13.76*	30.11*	36.80*	23.45*
Pb. 313 A_2 x 77/273 vs. 313B_2 x 77/273	12.38*	18.35*	-3.49	23.81*	16.15*	16.97*	8.71	9.21	-12.37*	18.91*	-24.27*	-3.64
Pb. 313 A_2 x CSSC 46-2 vs. 313B_2 x CSSC 46-2	12.97*	-5.99	34.91*	-2.89	12.65*	29.37*	3.41	10.52	10.22	5.91	-2.07	21.46*
Pb. 402A_3 x 77/273 vs. Pb. 402B_3 x 77/273	16.30*	2.94	26.28*	25.78*	-30.68*	-8.01	18.86*	10.74	-13.19*	31.99*	-1.49	-11.88
Pb. 402A_3 x ISK48 vs. Pb. 402B_3 x ISK48	32.7*	2.54	0.88	19.08*	-9.08	12.49	18.36*	8.73	26.91*	9.4	-7.19	-20.39*
81 A4 x G73-107 vs. 81B 4 x G73-107	-0.47	27.30*	25.16*	10.81	13.28*	-2.77	-6.01	3.51	-0.69	-2.57	7.28	1.67
81 A5 x H90/4-5 vs. 81 B5 x H90/4-5	11.56*	33.17*	-8.55	11.5	27.99*	4.1	-7.17	12.06	-8.79	-4.04	16.75*	-2.82
81 A5 x G73-107 vs. 81B 5 x G73-107	26.16*	-0.53	7.55	24.40*	-0.52	23.40*	3.83	-14.14	3.62	2.56	-7.45	31.82*
81 A5 x 77/28-2 vs. 81B5 x 77/28-2	14.76*	-12.22	0.75	9.6	12.18*	2.2	40.83*	-1.94	-4.39	33.05*	8.35	-1.23
SE (Sij)	5.87	6.9	6.37	6.53	5.54	6.6	8.85	9.69	5.98	7.29	5.61	8.8
C. D. (P=0.05)	11.51	13.52	12.49	12.8	10.86	12.94	17.35	18.99	11.72	14.29	11	17.25

Genotypes	Total tillers at maturity						Number of leaves/main stem					
	E1	E2	E3	E4	E5	E6	E1	E2	E3	E4	E5	E6
81 A_1 vs. 81 B_1	-2.85*	0.13	0.00	-0.08	0.39*	0.09	-0.47*	0.14	-0.18	-0.20*	0.21*	-0.20*
HMS 8A_1 vs. 8B_1	-0.61*	0.03	-0.06	0.05	-0.02	-0.37*	-0.27*	-0.01	-0.13	0.01	0.01	0.11
Pb. 313A_2 vs. 313B_2	-0.02	1.71*	0.10	0.09	0.43*	-0.10	0.22*	-0.02	0.02	-0.04	0.11	0.01
Pb. 402A_3 vs. 402B_3	-0.64*	-0.20*	0.30*	0.02	-0.02	-0.09	-0.08	-0.10	0.16	-0.08	-0.40*	0.22*
81 A_4 vs. 81 B_4	0.07	-0.01	0.03	0.01	0.36*	0.08	0.32*	0.14	0.15	-0.13	0.04	-0.10
81 A_5 vs. 81 B_5	-0.36*	0.01	-0.20*	-0.08	0.35*	-0.35*	0.06	-0.08	-0.06	0.01	-0.12	-0.25*
S. E(d)	0.12	0.09	0.08	0.07	0.12	0.13	0.09	0.12	0.10	0.10	0.09	0.08
C. D. (P=0.05)	0.24	0.18	0.16	0.14	0.24	0.25	0.18	0.24	0.20	0.20	0.18	0.16
F_1 hybrids												
81 A_1 x 77/273 vs. 81B_1 x 77/273	0.81	-0.93*	0.38	1.63*	0.80	-2.95*	-0.43	0.26	0.78*	0.10	0.10	-0.19
8 A_1 x Raj 42 vs. 8B_1 x Raj 42	-0.09	-0.13	-0.15	0.09	2.21*	0.92	0.96*	1.41*	0.22	0.29	0.09	-0.11
Pb. 313 A_2 x 77/273 vs.Pb. 313B_2 x 77/273	-0.19	0.31	-0.11	0.30	-2.36*	-0.19	-0.32	0.52	0.08	-0.46	-1.11*	-0.02
Pb. 313 A_2 x CSSC 46-2 vs.Pb. 313B_2 x CSSC 46-2	-0.18	0.61	0.29	-0.80	1.73*	3.01*	-0.32	0.12	0.08	0.64	-0.21	-1.62*
Pb. 402A_3 x 77/273 vs. Pb. 402B_3 x 77/273	0.03	0.12	0.21	0.09	-0.35	-0.87	0.78*	0.20	-0.26	0.27	-0.72*	0.38
Pb. 402A_3 x ISK48 vs. Pb. 402B_3 x ISK48	0.13	0.31	0.61	0.59	-0.04	1.24	0.27	0.00	-0.05	0.37	-0.14	-0.22
81 A_4 x G73-107 vs. 81B_4 x G73-107	0.12	0.33	0.35	0.28	-0.30	-2.11	-0.43	-0.05	0.16	0.13	-0.23	0.20
81 A_5 x H90/4-5 vs. 81 B_5 x H90/4-5	0.97*	0.70	-0.06	-0.53	0.21	1.82*	-2.16*	-0.13	-0.94*	-0.30	0.51	0.35
81 A_5 x G73-107 vs. 81B_5 x G73-107	-0.23	-0.10	-0.26	0.98	0.71	-0.97	0.54	0.07	0.45	0.00	-0.09	0.06
81 A_5 x 77/28-2 vs. 81B_5 x 77/28-2	-0.33	-0.10	0.24	-0.51	-0.19	0.32	0.04	0.18	-0.84*	0.19	0.52	-0.94
SE (Sij)	0.42	0.42	0.62	0.68	0.73	0.72	0.30	0.40	0.36	0.33	0.30	0.28
C. D. (P=0.05)	0.82	0.82	1.22	1.33	1.43	1.41	0.59	0.78	0.71	0.65	0.59	0.55

*Significant at P=0.05 level. E1 & E4–Unratoon early sown crop, E2 & E5–Ratoon crop, E3 & E6–Unratoon late sown crop.

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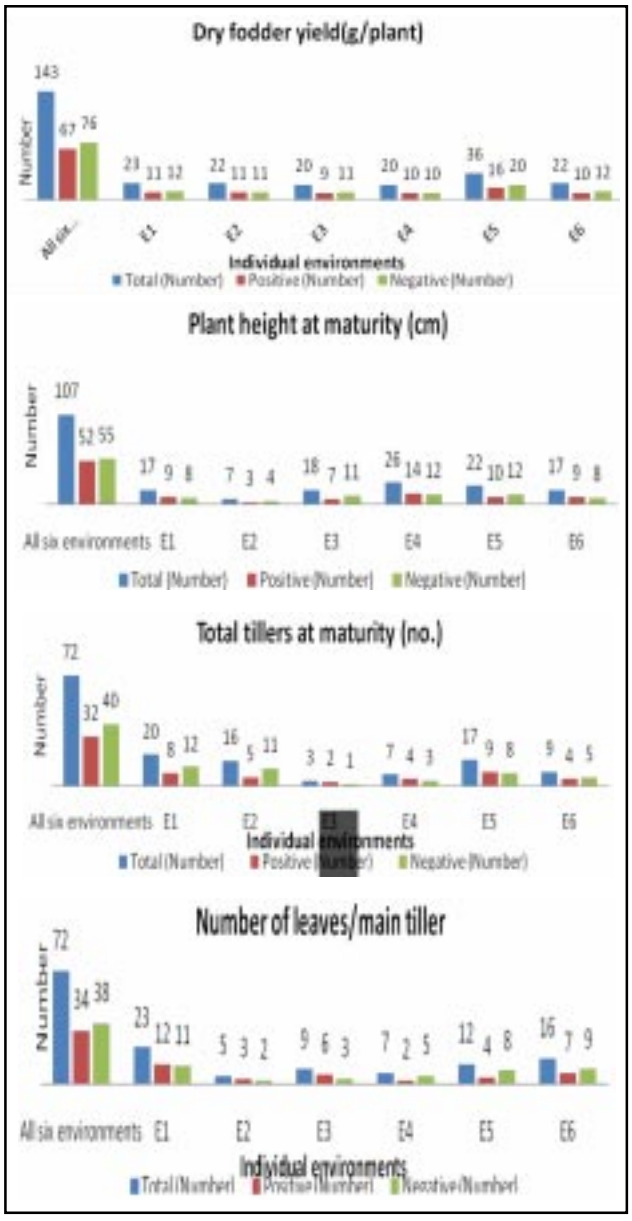

Fig. 2. Bar diagram depicting effect of cytoplasm on number of specific combining ability effects (total, positive, negative) for four characters in different environments.

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