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Effect of cytoplasm on downy mildew vulnerability in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract

Effect of cytoplasm on downy mildew vulnerability in pearl millet was studied in 144 hybrids developed by crossing six A- and six B- lines with 12 R- lines in a line x tester mating design. The six A- lines 81A1 and 8A$_1$ (A$_1$), Pb 313 (A$_2$), Pb 402A (A$_3$), 81A$_4$ and 81A$_5$ and their corresponding B- lines represented five different systems of cytoplasmic-genic male sterility. Three A- lines and eleven R- lines were resistant to downy mildew, the other three A- lines and one R- line were susceptible to downy mildew. The 24 parents and 144 crosses were grown separately in contiguous blocks in 2 R x 2.5 m x 0.45 m plots in randomized block design with two replications in four treatment environments (early sown non-ratooned crop, ratoon crop, late sown non-ratooned, multiple disease sick plot) during *kharif* 2000 and *kharif* 2001. The downy mildew incidence was recorded on all plants in the plot under natural as well as sick plot after 30 and 60 days of sowing. The analysis of variance showed that genotypes, parents, lines (A, B), testers, A x R, B x R hybrids differed significantly in all environments individually and on pooled basis. Differences due to A vs. B, A x R vs. B x R, (A x R vs. B x R) x E crosses contrasts were not significant in an individual environment and on pooled basis except for A- vs. B-lines at 30 days in late sown non-ratooned crop during *kharif* 2000. The comparison of downy mildew incidence means of A-lines with corresponding B-lines and array means of A x R crosses with that of B x R crosses also showed non-significant variation. This showed that cytoplasmic effects were not responsible for downy mildew susceptibility.

Key words: Pearl millet, downy mildew, vulnerability, cytoplasm

Introduction

The use of cytoplasmic-genic male sterility (CMS) in pearl millet [*Pennisetum glaucum* (L.) R. Br.] paved the way for grain yield augmentation with the development and release of first grain hybrid HB-1 by Athwal [1] using male sterile line Tift 23A and restorer BIL-3B. The higher productivity (≥75-100%) of superior genetically uniform hybrids attracted the farmers to cultivate them on a large scale. Before the cultivation of such hybrids, open pollinated varieties were the major source of seeds of this highly cross pollinated crop and downy mildew caused by *Sclerospora graminicola* never assumed economic dimensions, although downy mildew was reported as early as 1907. The disease appeared in wide epidemic form in 1970-71, 1978-80, 1984-85, 1992-93 on most popular hybrids. Pearl millet cultivation was at stake, and the A$_1$ cytoplasm that permitted commercial hybrid multiplication of hybrid seed was considered to be culpable. High grain yield losses (13-65%) were reported [2], and sometimes with no grain was harvested although an average 30% yield loss was recorded [3,4]. A significant correlation (r = 0.99) between downy mildew and grain yield was reported [5]. Potential vulnerability of the hybrid industry to disease and insect pest epidemics due to cytoplasmic uniformity, as witnessed in case of southern leaf blight (*Bipolaris maydis*) epidemic on the Texas cytoplasm-based maize hybrid in United States [6] was generally put forth as a strong argument for cytoplasmic diversification of hybrid cultivars. Safeeula [7] held the A$_1$ male sterile cytoplasm used in seed multiplication of all the hybrids to be responsible for increased incidence of downy mildew on them. Therefore, different sources of male-sterility-inducing cytoplasms were sought and several such as A$_2$, A$_3$ [8], Maiwa [9], A$_4$ [10] and A$_5$ [11], have been discovered. The association of A$_1$ cytoplasm with downy mildew [12, 13] and with smut [14] has been negated using male sterile (A) and male fertile (B) lines. Reports of association of smut with A$_1$ cytoplasm are conflicting [14, 15]. Thakur *et al.* [15] observed higher smut infection on hybrids on A-lines than on hybrids based on B-lines, suggesting that higher smut severity is linked with A$_1$ cytoplasm perhaps due to reduced male-fertility of the A$_1$ cytoplasm hybrids. Wilson and Hanna [16] observed no effects of the B$_1$, A$_1$ or A$_4$ cytoplasm on *Pyricularia*

grisea infection in the field or under green house. The influence of A_1 cytoplasm on the downy mildew incidence of hybrids can be studied by comparing the disease reaction of F_1 hybrids pairs which are identical in their genetic constitution but carry either A_1 or normal cytoplasm. The present study was undertaken to asses the role of cytoplasm in vulnerability of pearl millet to downy mildew, using different male sterile lines.

Materials and methods

The material for present study comprised 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 ($Pb313A_2$), A_3 ($Pb402A_3$), A_4 ($MS81A_4$) and A_5 ($MS81A_5$), their corresponding maintainer (B-) lines $81B_1$, $HMS8B_1$, $Pb313B_2$, $Pb402B_3$, $81B_4$ and $81B_5$ and twelve restorer (R-) lines *viz*., H90/4-5, H77/833-2, G73-107, 77/245, 77/273, CSSC 46-2, ISK48, ICR161, 77/180, 78/711, 77/28-2, Raj 42. Six male sterile lines and their corresponding six maintainer lines were crossed with twelve restorer lines in a line x tester mating design at ICRISAT, Hyderabad, during off-season (January-April, 2000). The 144 hybrids thus produced and their parents were grown separately in contiguous blocks in randomized block design with two replications in eight artificially created four treatment environments, each during *kharif* 2000 and *kharif* 2001, three (E1, E2, E3) at Research Farm, Bajra Section, Department of Plant Breeding, and one sick plot (SP) Department of Plant Pathology, CCS HAU, Hisar. The early sown non-ratooned crop and ratoon crop was sown on 5th June in 2000 and 25th June in 2001 at Research Farm, Bajra Section, CCS HAU, Hisar. 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 late sown non-ratooned treatment was sown on 14th July 2000 and 5th August 2001. The crop in pearl millet multiple disease sick plot, Department of Plant Pathology was sown on 15th July 2000 and 10th July 2001.

The plot size was 2R x 2.5m x 0.45m with 10 cm intra-row spacing. All the recommended agronomic practices were followed to raise a good crop. The downy mildew incidence was recorded on all plants in the plot under natural as well as sick plot condition during both two years 2000 and 2001 at 30 and 60 days after sowing. The analysis of variance was carried out in each of the environments according to Federer [17] and combined analysis of variance was performed according to the model given below:

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

Further

$$g_{ij} = p_i + t_j + (pt)_{ij} = pa_i + pb_i + t_j + (pt)a_{ij} + (pt)b_{ij}$$

$$e_{kl} = y_k + d_l + (yd)_{kl}$$

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

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

i = I, 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

Results and discussion

The genotypes, their component-parents and hybrids exhibited significant differences for downy mildew incidence in all the four treatment environments during both the years at both observation stages (30 days, 60 days) (Table 1). Significant differences in downy mildew incidence reaction were observed among parents (among lines and among testers) in all the treatment environments at both observation stages except for lines in E1 during 2000 and 2001 at 30 days and testers in E3 at 60 days. The lines also contracted significant downy mildew than the testers (lines vs. testers) in all the treatments except in E1 during 2000 and 2001 and E3 in 2000 at 30 days, where contrast was not significant. Among lines both A- and B- lines also showed significant downy mildew reaction at both the stages of record in all the treatment environments except E1 during both the years both (A- and B- lines), A- lines in SP in 2001, B-lines in E3 in 2000 at 30 days and A- lines in E1 in 2001 at 60 days. The A x R and B x R hybrids also expressed significant differences in downy mildew reaction in all the treatment environments at both observation stages in both the years. Comparison of downy mildew reactions of A- lines vs. B- lines and A x

Table 1. Analysis of variance for downy mildew incidence (%) at 30 and 60 days in four environments during two years

Source of variation	d.f	Downy mildew incidence (%) at 30 days								Downy mildew incidence (%) at 30 days							
		2000				2001				2000				2001			
		E1	E2	E3	SP	E1	E2	E3	SP	E1	E2	E3	SP	E1	E2	E3	SP
Replications	1	13.03	0.93	68.16	10.73	237.3	121.22	3.96	272.3	43.06	0.04	93.72	4.61	377.3	0.04	150.52	161.87
Genotypes (G)	167	48.20**	109.90**	61.05**	163.47**	48.10**	85.89**	125.15**	176.25**	68.24**	180.26**	95.25**	206.07**	73.83**	258.01**	178.35**	205.67**
Parents	23	58.04**	220.89**	84.04**	313.00**	47.67**	175.20**	154.98**	154.78**	79.51**	234.38**	73.48**	374.63**	93.93**	240.60**	190.25**	218.68**
Lines	11	26.98	226.31**	56.64**	194.99**	43.67	92.01**	170.86**	111.70**	42.30**	235.23**	90.48**	203.74**	90.74**	242.04**	157.54**	142.09**
A- lines	5	26.31	244.89**	79.54**	183.58**	43.2	117.44**	196.91**	71.04	48.31*	253.06**	129.11**	215.08**	61.14	248.86**	183.69**	112.45*
B- lines	5	32.56	252.94**	24.57	245.39**	52.45	83.54*	178.04**	157.01**	44.74*	262.29**	65.02*	227.05**	133.52**	282.64**	161.70**	198.18**
A- vs. B-lines	1	2.50	0.32	102.50*	0.003	2.19	7.16	4.67	88.51	0.02	10.72	29.61	30.49	24.85	4.90	5.97	9.93
Testers	11	91.22**	78.95**	114.14**	400.66**	55.51*	274.21**	90.47**	185.48**	117.17**	134.03**	36.51	547.58**	93.96**	210.63**	175.06**	272.25**
Lines vs. Testers	1	34.62	1722.60**	54.31	646.94**	5.44	1.20	689.85**	290.91**	74.65*	1328.99**	293.24**	351.92**	128.74*	554.61**	717.11**	471.82**
Hybrids (H)	143	46.95**	89.25**	57.78**	137.73**	48.51**	70.68**	118.28**	179.82**	66.87**	167.69**	99.41**	173.74**	70.83**	261.78**	176.40**	203.08**
P vs. H	1	1.92	510.37**	1.42	406.59**	0.01	205.96*	422.85**	158.91*	7.2	733.04**	0.01	953.65**	41.65	118.33	183.69*	276.69**
A x R hybrids	71	36.16**	95.25**	68.81**	163.31**	54.01**	64.19**	106.36**	175.73**	54.36**	170.20**	100.84**	203.72**	77.45**	225.68**	146.59**	195.75**
B x R hybrids	71	57.61**	84.47**	47.16**	113.83**	43.65**	78.17**	131.44**	186.36**	80.11**	167.53**	99.34**	146.14**	65.19**	300.85**	208.52**	212.59**
A x R vs B x R	1	55.23	1.34	27.57	16.99	3.20	0.24	29.21	6.16	14.41	0.01	2.97	4.03	0.49	50.97	12.95	48.53
Error	167	17.15	24.83	19.35	40.05	23.97	31.79	24.49	35.2	17.76	25.09	20.66	50.27	31.97	66.95	45.83	37.93

* and ** significant at P=0.05 and P=0.01, respectively; E1 = early sown non-ratooned crop, E2 = ratoon crop, E3 = late sown non- ratooned crop, SP = Sick plot

R hybrids vs. B x R hybrids were not significantly different in any of treatments at either of observation stage in except for A vs. B lines in E3 in 2000 at 30 days, which could be a human error. These results show that cytoplasm *per se* is not involved in differences in host susceptibility to downy mildew in pearl millet. The combined analysis of variance for downy mildew incidence on pooled basis in eight treatments, four each during both the years revealed significant differences for treatments / environments, years, dates, genotypes, parents, hybrids and various other contrasts (Table 2). The non-significance of mean squares due to A- vs. B-lines, A x R vs. B x R hybrids and (A x R vs. B x R) x E at both observation stages confirms that sterile cytoplasm, of any system, has no specific role to play in downy mildew vulnerability.

Table 2. Combined analysis of variance for Downy mildew incidence in four treatment environments during two years

Source of variation	d.f.	Mean sum of squares	
		Downy mildew incidence at 30 days (%)	Downy mildew incidence at 60 days (%)
Rep. in environments	8	90.96	103.89
Environments (E)	7	1669.91**	3198.41**
Year	1	883.78**	3251.20**
Date	3	3088.39**	6143.53**
Year x Date	3	513.48**	235.70**
Genotypes (G)	167	485.35**	848.66**
Parents (P)	23	720.60**	1129.85**
Lines	11	483.76**	851.89**
A-lines	5	559.16**	992.12**
B-lines	5	489.54**	879.20**
A- vs B-lines	1	78.03	14.19
Testers	11	846.11**	1203.50**
Line vs Tester	1	1945.31**	3377.43**
Hybrids (H)	143	443.39**	799.13**
P vs H	1	1075.22**	1464.43**
A x R hybrids	71	457.39**	768.04**
B x R hybrids	71	435.62**	840.86**
A x R vs. B x R	1	1.52	43.02
G x E	1169	47.53**	59.58**
P x E	161	69.72**	53.65**
H x E	1001	43.66**	60.09**
(P vs H) x E	7	90.41**	121.32**
(A x R) x E	497	43.78**	58.08**
(B x R) x E	497	43.87**	62.77**
(A x R vs B x R) x E	7	19.78	13.04
Error	1336	27.11	37.05

**Significant at 1 % level

The downy mildew incidence (%) of A-line, B-lines and their array means recorded at 30 days and 60 days are presented in Tables 3 and 4. The downy mildew incidence in ratoon / regenerated crop was significantly higher than that on early sown non-ratooned or late sown non-ratooned crop during both the years. This indicates that the juvenile plant parts of regenerating plants are more vulnerable to this disease. Mohan and Chahal [18] also reported increased downy mildew incidence in pearl millet after cutting at 30 days after sowing. A/B- pairs 313A and 313B and 402Aand 402B were free from downy mildew in most of the environments at both observation stages during both years, but A-and B-lines downy mildew incidence differences were non-significant showing their resistance to be due to nuclear genes that are common among the A-line and B-line component of each of these A/B pairs. Downy mildew incidence of A/B- pairs of 81A isolines i.e. $81A_1$, $81A_4$ and $81A_5$ was almost similar at both observation stages during both years with non-significant differences, but these lines were susceptible at both observation stages in all the treatments / environments during both years. The downy mildew incidence of hybrids (i.e. resistance and susceptibility of arrays) of both A- and B-pairs of all six lines was similar. Almost similar disease reactions within all A/B- line pairs confirm the non-involvement of cytoplasm in downy mildew vulnerability.

In 1970s when the cultivation of hybrids was at a stake due to succumbing of all hybrids to downy mildew, the A_1 cytoplasm was considered to be responsible for increased incidence of downy mildew in them. But the reports of Yadav *et al.* [12] and Yadav [13] and Sagar and Kumar [19] overruled the apprehension of association of cytoplasm being responsible for downy mildew susceptibility. The availability of downy-mildew-resistant lines based on Tift $23A_1$ cytoplasm [20] further substantiates it. Also, the resistance of hybrids even involving susceptible male-sterile line and resistant pollinator watched over the years proves that it is not the cytoplasm, but the interaction of cytoplasm and nuclear genes are greatly responsible for difference in resistance expressed in the hybrids. Non-significance of A vs. B, A x R vs. B x R hybrid comparisons in individual environments and their interaction with

Table 3. Mean downy mildew incidence (%) of pearl millet parents and their arrays at 30 days

	2000								2001									
	E1		E2		E3		SP		E1		E2		E3		SP		Overall mean	
Parents	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line
81A & 81B	3.05 (9.47)	0.00 (4.05)	17.86 (24.94)	19.52 (24.95)	2.55 (8.87)	0.00 (4.05)	25.02 (30.33)	9.06 (14.8)	2.15 (8.35)	0.00 (4.05)	5.01 (11.48)	7.16 (13.34)	14.26 (22.57)	14.91 (23.1)	11.46 (19.9)	2.80 (9.17)	10.17 (16.99)	6.68 (12.19)
8A & 8B	2.15 (8.35)	3.55 (10.02)	15.81 (23.48)	3.55 (10.02)	3.35 (9.8)	0.00 (4.05)	10.11 (18.64)	0.00 (4.05)	10.01 (15.48)	10.01 (15.48)	0.00 (4.05)	11.01 (19.63)	18.51 (25.84)	10.11 (18.98)	9.11 (18.05)	12.51 (17.19)	8.63 (15.46)	6.34 (12.43)
313A & 313B	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	3.85 (10.34)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	12.76 (21.34)	4.41 (10.9)	1.59 (6.21)	1.03 (5.69)
402A & 402B	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	2.75 (9.11)	0.00 (4.05)	0.00 (4.05)	3.55 (10.02)	5.55 (11.98)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	2.05 (8.21)	0.00 (4.05	0.7 (5.31)	1.04 (5.67)
$81A_4$ & $81B_4$	2.30 (8.55)	2.15 (8.35)	13.36 (21.83)	24.27 (28.79)	7.71 (16.58)	5.05 (11.52)	18.21 (24.16)	31.42 (34.28)	0.00 (4.05)	0.00 (4.05)	9.41 (18.12)	0.00 (4.05)	13.86 (22.26)	18.01 (25.42)	13.61 (21.97)	18.86 (25.08)	9.81 (17.19)	12.47 (17.69)
$81A_5$ & $81B_5$	5.10 (13.65)	5.15 (13.72)	24.22 (29.4)	24.27 (29.43)	10.71 (19.19)	3.55 (10.02)	7.55 (13.65)	18.71 (25.54)	0.00 (4.05)	5.55 (11.98)	13.56 (20.95)	4.55 (11.05)	13.06 (21.52)	11.16 (19.4)	18.41 (25.74)	19.56 (25.78)	11.58 (18.52)	11.56 (18.36)
Mean	2.10 (8.02)	1.81 (7.37)	11.87 (17.96)	12.39 (17.72	4.05 (10.42)	1.43 (6.29)	10.74 (16.81)	11.43 (16.83)	2.03 (6.67)	2.59 (7.27)	4.66 (10.45)	3.79 (9.36)	9.95 (16.71)	9.03 (15.83)	11.23 (19.2)	9.69 (15.36)	7.08 (13.28)	6.52 (12)
Mean (A+B)	1.96 (7.69)		12.13 (17.84)		2.74 (8.35)		11.09 (16.82)		2.31 (6.97)		4.22 (9.9)		9.49 (16.27)		10.46 (17.28)		6.80 (12.64)	
Array mean																		
A/BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR
81A&81B	(1.61) (6.62)	4.05 (9.96)	4.36 (10.07)	4.19 (10.19)	3.51 (9.30)	1.95 (6.89)	7.02 (12.48)	5.60 (11.03)	1.43 (6.38)	1.61 (6.62)	2.50 (7.61)	3.01 (7.64)	3.66 (9.55)	1.42 (6.23)	6.82 (13.25)	6.13 (11.89)	3.86 (9.41)	3.49 (8.81)
8A&8B	1.73 (6.78)	1.73 (6.68)	4.65 (10.26)	3.84 (9.30)	2.44 (7.35)	2.36 (7.77)	6.84 (12.00)	6.70 (12.33)	1.64 (6.63)	1.98 (6.94)	4.14 (9.57)	5.19 (10.60)	6.25 (11.54)	9.95 (14.66)	5.01 (11.17)	7.00 (12.60)	4.09 (9.41)	4.84 (10.11)
313A&313B	1.38 (6.02)	1.91 (6.63)	2.19 (7.13)	3.27 (8.61)	1.96 (6.98)	1.45 (6.47)	2.06 (7.06)	2.51 (7.66)	0.68 (5.12)	0.23 (4.48)	2.35 (7.51)	1.42 (6.20)	3.00 (7.76)	4.54 (9.89)	9.24 (13.69)	6.80 (11.53)	2.86 (7.66)	2.77 (7.68)
402A & 402B	0.19 (4.43)	0.18 (4.41)	0.00 (4.05)	0.41 (4.84)	0.20 (4.44)	0.37 (4.62)	0.56 (4.99)	0.78 (5.19)	2.92 (7.77)	2.37 (7.12)	1.77 (6.68)	1.16 (5.81)	2.34 (7.44)	3.45 (9.14)	5.23 (11.06)	4.76 (10.43)	1.65 (6.36)	1.69 (6.45)
$81A_4$ & $81B_4$	1.76 (6.56)	1.11 (5.72)	3.44 (9.13)	2.15 (6.89)	3.31 (8.35)	2.52 (7.44)	4.40 (9.86)	6.54 (11.91)	3.06 (7.72)	2.48 (7.19)	2.19 (7.41)	2.60 (7.73)	2.97 (8.50)	3.36 (8.73)	6.53 (12.25)	9.69 (15.82)	3.46 (8.72)	3.81 (8.93)
$81A_5$ & $81B_5$	1.76 (6.76)	3.56 (9.02)	4.28 (9.76)	4.80 (9.76)	2.70 (8.09)	2.70 (7.60)	9.75 (15.11)	4.64 (10.46)	1.96 (6.95)	1.92 (6.95)	2.60 (8.03)	4.01 (9.17)	3.46 (8.96)	3.31 (8.92)	9.03 (14.85)	9.40 (15.76)	4.44 (9.81)	4.29 (9.71)
Mean	1.41 (6.19)	2.09 (7.07)	3.15 (8.40)	3.11 (8.26)	2.35 (7.42)	1.89 (6.80)	5.11 (10.25)	4.46 (9.76)	1.95 (6.76)	1.76 (6.55)	2.59 (7.80)	2.90 (7.86)	3.62 (8.96)	4.34 (9.60)	6.98 (12.71)	7.29 (13.00)	3.39 (8.56)	3.48 (8.61)
CD at 5%		8.12		9.77		8.62		12.4		9.6		11.05		9.70		11.63		

E1 = early sown non- ratooned crop, E2 = ratoon crop, E3 = late sown non -ratooned crop, SP = Sick plots; Figures in parentheses indicate angular transformation values (degrees) of downy mildew incidence

Table 4. Mean downy mildew incidence (%) of pearl millet parents and their arrays at 60 days

	2000								2001									
	E1		E2		E3		SP		E1		E2		E3		SP		Overall mean	
Parents	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line	A line	B line
81A & 81B	4.71 (13.06)	3.55 (10.02)	20.56 (27.18)	22.27 (27.76)	78.00 (16.82)	2.15 (8.35)	33.37 (35.42)	18.22 (20.73)	2.15 (8.35)	3.35 (9.8)	22.52 (28.62)	31.88 (34.63)	14.26 (22.57)	14.41 (22.69)	15.06 (23.22)	9.41 (18.27)	15.08 (20.69)	13.15 (21.35)
8A & 8B	2.15 (8.35)	3.55 (10.02)	14.46 (22.53)	13.71 (21.31)	3.35 (9.8)	1.70 (7.72)	13.71 (21.31)	2.95 (9.35)	10.01 (15.48)	18.56 (25.56)	17.71 (25.21)	24.57 (29.44)	18.51 (25.84)	12.66 (21.25)	13.66 (21.83)	15.66 (22.72)	11.70 (22.09)	11.67 (24.73)
313A & 313B	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	2.15 (8.35)	2.80 (9.17)	3.85 (10.34)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	0.00 (4.05)	2.05 (8.21)	2.15 (8.35)	14.21 (22.53)	4.41 (10.9)	2.38 (9.71)	1.57 (6.84)
402A & 402B	0.00 (4.05)	0.00 (4.05)	2.05 (8.21)	5.05 (11.52)	0.00 (4.05)	0.00 (4.05)	3.55 (10.02)	5.55 (11.98)	0.00 (4.05)	0.00 (4.05)	2.15 (8.35)	2.80 (9.17)	0.00 (4.05)	0.00 (4.05)	2.05 (8.21)	3.15 (9.58)	1.23 (6.16)	2.07 (6.71)
$81A_4$ & $81B_4$	4.55 (11.05)	3.86 (12.02)	19.61 (26.43)	27.47 (31.79)	10.91 (19.67)	8.71 (17.61)	20.97 (26.96)	31.42 (34.28)	3.15 (9.58)	4.55 (11.05)	15.46 (23.42)	14.81 (23.02)	16.81 (24.49)	20.27 (26.95)	24.27 (28.95)	32.73 (34.39)	14.47 (21.61)	17.98 (23.85)
$81A_5$ & $81B_5$	7.36 (16.2)	7.40 (16.25)	28.32 (31.83)	28.32 (31.83)	14.36 (22.66)	9.31 (17.64)	22.32 (27.03)	25.56 (29.71)	8.66 (17.03)	11.11 (16.25)	27.62 (30.95)	9.11 (14.83)	17.01 (24.7)	12.81 (20.61)	22.42 (28.41)	24.11 (29.57)	18.51 (25.26)	15.97 (20.31)
Mean	3.13 (9.46)	3.06 (9.4)	14.17 (20.04)	16.14 (21.37)	6.10 (12.84)	4.00 (10.62)	16.12 (21.65)	14.59 (19.4)	4.00 (9.75)	6.26 (11.79)	14.24 (20.09)	13.86 (19.19)	11.44 (18.31)	10.38 (17.31)	15.28 (22.19)	14.91 (20.9)	10.56 (16.79)	10.40 (16.25)
Mean (A+B)	3.09 (9.43)		15.15 (20.7)		5.05 (11.73)		15.36 (20.52)		5.13 (10.77)		14.05 (19.64)		10.91 (17.81)		15.09 (21.55)		10.48 (16.52)	
Arrays A/BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR	AxR	BxR
81A & 81B	3.48 (9.64)	5.08 (11.14)	8.56 (14.66)	9.08 (14.89)	5.08 (11.32)	4.28 (10.42)	9.47 (14.96)	7.65 (13.63)	2.04 (7.55)	2.26 (7.70)	10.60 (15.25)	7.18 (12.36)	5.52 (11.63)	2.94 (8.54)	8.29 (14.52)	8.75 (14.33)	6.63 (12.46)	5.90 (11.72)
8A & 8B	2.99 (8.84)	2.66 (7.94)	7.66 (13.09)	6.84 (12.70)	4.24 (9.78)	4.78 (10.56)	9.56 (15.11)	11.50 (17.69)	3.05 (8.40)	4.21 (10.12)	9.75 (14.98)	16.79 (19.71)	9.91 (15.28)	14.88 (18.19)	8.10 (14.82)	10.77 (16.67)	6.91 (12.45)	9.05 (13.98)
313A & 313B	1.71 (6.51)	2.15 (7.07)	3.37 (8.31)	4.98 (10.48)	2.88 (8.38)	2.80 (7.94)	3.51 (9.25)	3.99 (9.64)	1.35 (6.11)	0.68 (5.30)	9.94 (14.67)	6.37 (11.82)	6.06 (11.26)	6.70 (12.16)	11.27 (16.14)	9.95 (15.64)	5.01 (9.86)	4.70 (9.87)
402A & 402B	0.44 (4.87)	0.18 (4.41)	1.20 (6.21)	1.10 (5.75)	1.01 (5.81)	0.86 (5.50)	1.63 (6.83)	2.17 (7.26)	5.34 (10.59)	4.39 (9.34)	6.44 (12.05)	5.96 (12.06)	4.20 (9.69)	4.54 (10.25)	7.13 (13.45)	6.22 (12.54)	3.42 (8.38)	3.18 (8.09)
$81A_4$ & $81B_4$	2.22 (7.24)	2.47 (7.59)	6.05 (11.87)	5.14 (10.69)	4.74 (10.11)	4.04 (9.47)	7.41 (13.59)	8.52 (14.51)	3.55 (8.41)	3.20 (8.51)	6.90 (12.71)	11.15 (16.46)	4.93 (10.62)	6.32 (12.30)	9.13 (15.72)	12.85 (19.57)	5.62 (11.22)	6.71 (12.18)
$81A_5$ & $81B_5$	2.58 (8.17)	4.20 (9.80)	7.33 (13.19)	7.63 (12.88)	4.81 (10.70)	5.15 (10.99)	13.67 (19.00)	7.71 (14.61)	2.17 (7.49)	2.68 (8.07)	9.72 (15.10)	13.13 (17.40)	5.64 (11.27)	5.56 (10.85)	12.08 (17.83)	12.58 (18.64)	7.25 (12.84)	7.33 (12.81)
Mean	2.23 (7.54)	2.79 (7.99)	5.69 (11.22)	5.79 (11.23)	3.79 (9.35)	3.65 (9.15)	7.54 (13.12)	6.92 (12.89)	2.91 (8.09)	2.9 (8.17)	8.88 (14.13)	10.09 (14.97)	6.04 (11.62)	6.82 (12.05)	9.33 (15.41)	10.18 (16.23)	5.8 (11.20)	6.14 (11.44)
CD at 5%		8.26		9.82		8.91		13.90		11.08		16.04		13.02		12.07		

E1 = early sown non-ratooned crop, E2 = ratoon crop, E3 = late sown non-ratooned crop, SP = Sick plots; Figures in parentheses indicate angular transformation values (degrees) of downy mildew incidence

environments (A x R vs. B x R) x E both at 30 and 60 days of downy mildew incidence recorded in five systems of male-sterility ruled out the culpability of the cytoplasm for downy mildew susceptibility in pearl millet. There seems no reason to be alarmed about the cytoplasm to be a cause for vulnerability of the crop to downy mildew. However, diversification of cytoplasmic male-sterile lines and systems would be a good defense to avoid any catastrophe.

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