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Genetic dissection of temperature tolerance in pearl millet (*Pennisetum glaucum*)

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ABSTRACT

Genetic control of temperature tolerance was investigated in pearl millet at seedling stage. Ten parents were selected through a field screening technique. They were crossed in a diallel manner. Fortyfive F_1 hybrids along with their 10 parents were tested for performance in randomized block design with three replications under supra-optimal temperature exposure at seedling stage. The experiment was conducted in three environments at different dates of sowing from May to July 2005. The Griffings method of diallel analysis was used to obtain the genetic estimates. Variances due to general combining ability and specific combining ability for all the characters studied, viz seedling thermo-tolerance index, seed to seedling thermo-tolerance index, germination, emergence rate, leaves/seedling, seedling height, seedling fresh weight, seedling dry weight were highly significant in all the three environments (two stress and one normal) indicating the importance of both additive and non-additive genetic variances. The non-additive (dominance) component was more prominent for all the characters. It suggested that heterosis breeding could be successful. The genotype 'CVJ 2-5-3-1-3' and '(77/371×BSECT CP 1)' were identified as the best general combiners for both the heat tolerance indices. Seven hybrds, namely, 'H77/833-2×96AC-93', '1305×96AC-93', '(77/371×BSECT CP-1)×Togo II', 'H77/29-2×CVJ 2-5-3-1-3', '1305×99HS-18', 'G73 107×77/245' and 'H77/833-2×H77/29-2' were identified having high values of heat tolerance indices seedling thermo-tolerance index and seed to seedling thermo-tolerance index. The estimates of additive genetic variance and narrow sense heritability for seedling thermo-tolerance index and seed to seedling thermo-tolerance index were high.

Key words: Combining ability, Diallel analysis, Gene action, *Pennisetum glaucum*, Seedling thermo-tolerance index, Seed to seedling thermo-tolerance index, Supra-optimal temperature tolerance

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most important staple crop of millions of people in the semi-arid and arid regions of Asia and sub-Saharan Africa (Arya and Yadav 2009).The temperature is one of the key climatic factors and has profound effect on the growth and development of the pearl millet. No modification of plant response to high temperature is possible through artificial means. Breeding work on the genectic variations is the sole route to have the tolerant plants for commercial cultivation. However, to our knowledge, low information is available on the inheritance of supra-optimal temperature tolerance at seedling establishment stage in pearl millet.

The objective of this study was to understand the nature and magnitude of different types of gene actions in controlling the inheritance of various traits for supra-optimal temperature tolerance in pearl millet. The study also aimed at classification of the parental genotypes and their hybrids relative to the combining ability effects. Such classification would help identify good general combiners to be used as donor parents for the improvement of the traits and specific cross-combinations for the utilization of heterosis effect through the development of hybrid and/or isolation of superior segregates in advance generations of segregation.

MATERIALS AND METHODS

Ten genotypes of pearl millet selected on the basis of different response to supra-optimal temperature tolerance(Peacock *et al*. 1993). Of these 10 genotypes, seven genotypes, viz 'H77/833-2', 'G73 107', 'CVJ 2-5-3-1-3', '77/371×BSECT CP 1', '96AC 93', 'Togo II' and '99HS 18' were tolerant and three ones ('H77/29-2', '77/245' and '1305') were susceptible. These were used as parents and were crossed in a half-diallel mating system (excluding reciprocals) during rainy (*kharif*) season 2004 to produce 45 F_1 hybrids. These ten parents along with 45 hybrids were

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tested for performance in randomized block design with three replications under supra optimal temperature exposure at seedling stage in three environments created through dates of sowing so as to conduct the experiment under different range of temperatures during May–July 2005.

Each genotype was grown in three rows each of three m length spaced 30 cm apart. Fifteen seeds were dibbled in each row at a distance of 10 cm each. The field was given medium irrigation and precisely levelled before sowing. The seeds were sown in the absence of a mechanized planter. Marked wooden sticks were used to ensure the placement of seed at uniform depth. The stick was inserted into the soil up to 4 cm mark, tilted to one side cutting an angle of about 30°C, making space for the seed. The seed (one) was dropped along the body of stick. The seed would settle in the bottom on gentle pull-out of the stick.

The emphasis of investigation was centred on to observe germination, survival and mortality of the seedlings. The seedlings were inspected every day in the morning. The seedlings which had died due to heat desiccation were marked by fixing a small wooden stick along their side as a check against the loss of dead seedlings. Process was continued up to a date till the surviving seedlings were established and there was no more mortality. The experiment was conducted at the research area of Department of Plant Breeding of the University, Hisar (latitude: 29° 10'N, longitude: 75° 46'E, and 215.2 m above mean sea level), located in subtropical region of Haryana, India. The soil was sandy loam (61% sand, 10.7% silt and 28.3% clay) in texture. Standard agronomic package of practices were taken to raise a healthy crop. A condition of no-drought was maintained in order to determine the exclusive effect of temperature at seedling stage. This was maintained by measuring the moisture status of the soil by gravimetric method on alternate days. The soil samples were taken from a depth of 5 cm, 10 cm and 20 cm. The soil surface temperature was measured by a soil thermometer at soil surface, temperature at 5 cm and 100 cm (1 m) above the soil surface were recorded between 2 PM and 2.30 PM daily.

Data were recorded on following traits, viz seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER), number of leaves/seedling (two-week stage), seedling height (two-week stage), seedling fresh weight (g) (four-week stage), seedling dry weight (g) (four-week stage). The data for seedling height and number of leaves/seedling was recorded on 10 random seedlings/replication. These seedlings were tagged for computation of seedling fresh weight and seedling dry weight parameters, destructive sampling was done by uprooting five random plants (out of ten plants) per genotype per replication. Uprooted plants were kept in oven at 75°C temperature for drying and seedling dry weight (g) was taken when constant weight was obtained. Rate of emergence of the seedlings was calculated by counting the seedlings germinated on daily basis from third day of sowing to the day when the seedling emergence was completely stopped.

$$\text{Emergence rate (ER)} = \frac{\text{No. of normal seedlings}}{\text{Days to first count}} + \text{--------} + \frac{\text{No. of normal seedlings}}{\text{Days to final count}}$$

Seedling thermo-tolerance index (STI) was calculated as the ratio of number of seedling survived to the number of seedling emergence, expressed in percentage. Seed to seedling thermo-tolerance index (SSTI) was calculated as the ratio of seedling survival to the number of seedling expected to emerge, expressed in percentage. The SSTI is an extension of STI by taking expected germination into account. It was necessary to correct the effect of under soil mortality (USM). The germination under monsoon environment of the same lot of spare seed was taken as expected germination in this experiment. Analysis of variance for randomized block design (RBD), diallel analysis of Griffing's Method 2, Model 1, variances due to GCA and SCA and correlations among the various characters were calculated (Sharma 1998).

RESULTS AND DISCUSSION

The maximum soil temperature rise up to 63.0°C in E_2, was about 18°C higher than the normal atmospheric temperature measured at 1 m above the soil surface (Figs 1, 2). This excessive heat was responsible for mortality of seedlings. Many a seedlings were found desiccated at the point of contact, besides the desiccation at the tips. The temperature around the tip level, ie 5 cm above the soil surface also reached up to an extent of 50°C (Fig 3). It could therefore be concluded that the seedlings had to survive in a really high temperature, ie 50°C (at tip level) and 63°C at contact level. The fact remains that the moisture level remained above the permanent wilting point (Fig 4). The drought effect was therefore not in the play.

The seedling thermo-tolerance index (STI) of the hybrids recorded values as low as 53 and as high as 82. Among the

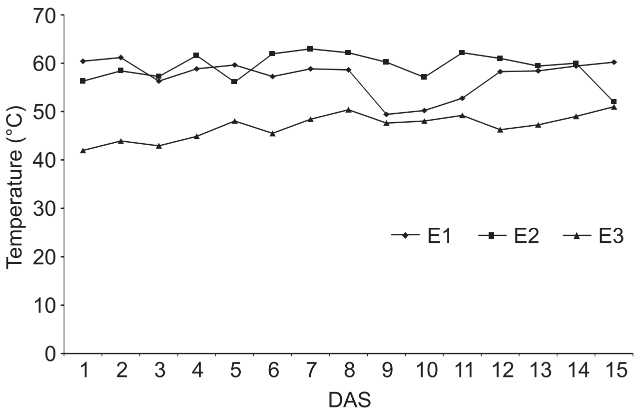

Fig 1 Soil surface temperature in different environments

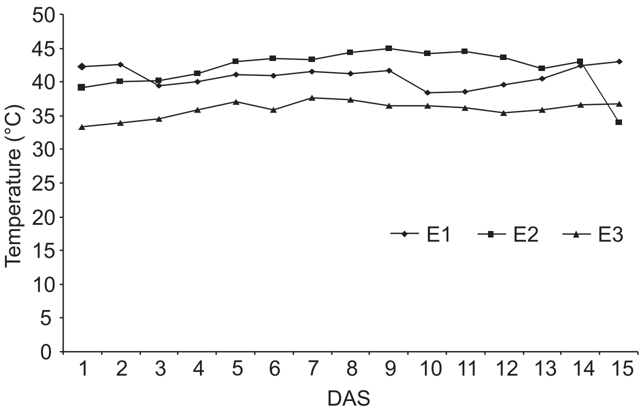

Fig 2 Air temperature in different environments

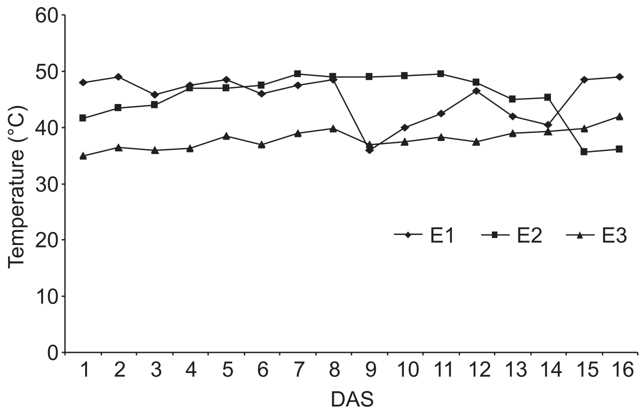

Fig 3 Temperature 5 cm above the soil surface in different environments

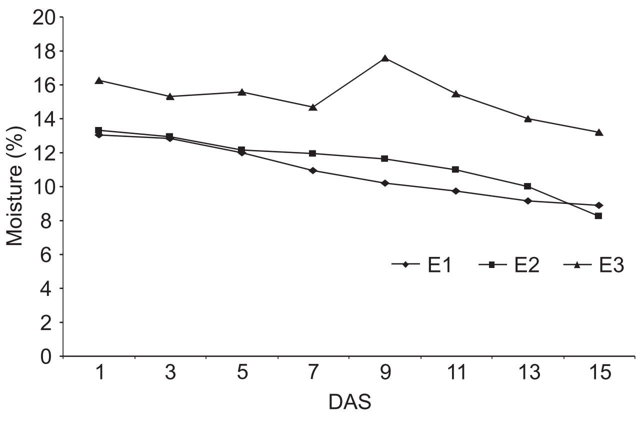

Fig 4 Soil moisture status in different environments

hybrids 'H77/29-2×77/245' and 'H77/833-2×96AC 93' were emerged as highly tolerant genotypes. Seed to seedling thermo-tolerance index (SSTI) which is expected to be more regrous index changed the values of the STI based on the variation in germination in normal environment (E_3). The reductions in values were not strictly proportional to the STI. Here the values ranged between 46 and 73 (Table 1).

The analysis of variance for eight different characters in three different environments (two stress and one normal) was carried out and the results showed significant genotypic differences for all the characters in all the three environments. Significance of the mean squares associated with parents vs. hybrids indicated presence of average heterosis for all the characters. That no variability was observed for seedling thermo-tolerance index and seed to seedling thermo-tolerance index in the E_3. In this environment no seedling mortality was observed and the germination was taken as standard. The values for STI and SSTI were therefore equal and highest for all the genotypes in this environment and hence no variation was observed. Further analysis was therefore not carried out for this environment.

The results obtained from analysis of variance for combining ability revealed that both additive (GCA) and non-additive (SCA) genetic variances were highly significant in all the three environments played an important role in the genetic control of the seedling traits. Krishnaiah *et al*. (2002) reported the importance of both additive and non-additive type of gene action for the inheritance.

Combining ability effects

A consideration of the GCA and SCA effects might be of help in isolating suitable genotypes for conventional breeding work. High GCA effects of the parents are mainly due to additive type of gene action and additive × additive type of gene interaction, which is fixable in the segregating generations. Thus, to enable isolation of superior segregates in the subsequent generations, selection of parents for hybridization should be made on the basis of their GCA-effects (Banerjee and Kole 2009).

The parent 'CVJ 2-5-3-1-3' was identified as the best general combiner for STI, followed by four other parents 'H77/833-2', '(77/371×BSECT CP 1)', '96AC 93' and '99HS 18' which exhibited high GCA effect (Table 2). The parents '(77/371×BSECT CP 1)' and 'G73 107' exhibited highest GCA effect for SSTI. The parent 'CVJ 2-5-3-1-3' was the good general combiner for seedling thermo-tolerance index (STI) and number of leaves/seedling. While, the parent 'H77/833-2' was good general combiner for STI only. The parent '(77/371×BSECT CP-1)' had high GCA effect for STI and SSTI as well as for germination, emergence rate (ER) and seedling height (cm) in all the environments. The parent '96AC 93' showed good general combining ability for STI, SSTI, seedling fresh weight (g) and seedling dry weight (g). The parents which showed the good GCA for both STI and SSTI were '(77/371×BSECT CP 1)' and '96AC 93'.

The parent G73 107 also showed the good GCA for SSTI, leaves/seedling in all environments and germination (%) in stress environments only. The overall result, however, maintained the trend that good per-se performer were also the good combiner for this trait and reverse was also true. The magnitude of SCA effects, of course differed for specific crosses in different environment but the direction (+ve or –ve) generally remained the same. Ten cross combinations,

Table 1 Mean performance of the parents and the crosses for different characters

Genotype	Germination (%)				Rate of emergence*				STI* (%)				SSTI* (%)			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
'H77/833-2'	39.41	37.37	61.64	46.14	40.37	41.09	42.79	41.42	78.30	73.87	90.00	80.72	44.98	41.33	90.00	58.77
'H77/29-2'	55.13	47.26	60.92	54.43	28.15	49.80	32.58	36.84	48.35	44.95	90.00	61.10	44.41	36.02	90.00	56.81
'G73-107'	50.37	48.26	59.18	52.60	45.34	41.32	44.81	43.82	61.87	54.13	90.00	68.66	52.13	44.60	90.00	62.24
'77/245'	47.47	46.24	55.65	49.78	36.25	46.04	40.47	40.92	43.85	35.80	90.00	56.55	38.03	30.40	90.00	52.81
'CVJ 2-5-3-1-3'	48.24	48.32	68.97	55.18	50.44	49.07	49.60	49.70	71.93	68.13	90.00	76.69	49.59	47.85	90.00	62.48
'1305'	43.26	38.91	54.04	45.40	33.76	50.56	35.73	40.02	39.03	32.81	90.00	53.95	32.11	24.52	90.00	48.88
'77/371×BSECT CP 1'	47.47	45.02	63.20	51.90	49.34	50.75	50.65	50.25	69.52	67.06	90.00	75.52	50.56	46.71	90.00	62.42
'96AC 93'	46.51	38.18	57.22	47.30	43.12	49.15	47.53	46.60	66.60	60.01	90.00	72.20	52.12	39.20	90.00	60.44
'Togo II'	46.13	39.37	52.76	46.09	42.45	47.37	47.97	45.93	71.98	68.61	90.00	76.86	59.80	47.67	90.00	65.82
'99HS 18'	45.75	38.23	62.47	48.82	43.17	46.59	47.46	45.74	75.94	73.19	90.00	79.71	51.54	41.72	90.00	61.09
'H77/833-2×H77/29-2'	57.87	52.95	67.33	59.38	49.64	50.15	49.89	49.89	68.03	65.04	90.00	74.36	58.08	51.34	90.00	66.47
'H77/833-2×G73-107'	54.72	44.17	64.05	54.31	54.48	54.22	52.39	53.70	72.31	67.69	90.00	76.67	59.80	45.56	90.00	65.12
'H77/833-2×77/245'	40.76	37.07	55.04	44.29	52.17	54.46	52.38	53.00	66.27	62.24	90.00	72.84	46.90	40.37	90.00	59.09
'H77/833-2× CVJ 2-5-3-1-3'	48.43	43.00	58.56	50.00	48.62	49.56	49.13	49.11	70.61	65.19	90.00	75.27	55.75	46.32	90.00	64.03
'H77/833-2×1305'	32.96	27.80	45.21	35.33	50.76	49.07	52.38	50.74	37.32	32.65	90.00	53.32	27.65	20.50	90.00	46.05
'H77/833-2×(77/371× BSECT CP 1)'	56.36	55.39	62.58	58.11	44.89	52.19	50.15	49.08	69.81	64.82	90.00	74.88	61.46	56.80	90.00	69.42
'H77/833-2×96AC 93'	57.20	55.15	63.35	58.57	48.00	51.86	50.75	50.21	78.33	77.86	90.00	82.06	66.03	62.56	90.00	72.87
'H77/833-2×Togo II'	48.62	34.53	57.09	46.75	50.36	48.29	49.11	49.25	61.90	55.00	90.00	68.97	52.14	33.39	90.00	58.51
'H77/833-2×99HS 18'	45.75	44.18	54.47	48.13	50.41	50.74	50.06	50.40	58.00	50.73	90.00	66.25	48.46	41.33	90.00	59.93
'H77/29-2×G73-107'	56.15	49.62	62.73	56.17	50.23	55.35	51.65	52.41	61.43	55.01	90.00	68.81	55.40	44.41	90.00	63.27
'H77/29-2×77/245'	54.72	51.64	62.81	56.39	47.45	50.31	50.28	49.35	55.72	51.75	90.00	65.82	49.01	43.45	90.00	60.82
'H77/29-2×CVJ 2-5-3-1-3'	54.94	51.24	65.36	57.18	48.04	53.16	49.57	50.26	75.96	80.76	90.00	82.24	60.93	56.80	90.00	69.24
'H77/29-2×1305'	38.04	38.26	55.11	43.80	35.96	47.24	43.87	42.36	63.62	70.75	90.00	74.79	42.30	45.17	90.00	59.16
'H77/29-2×(77/371× BSECT CP 1)'	63.69	48.47	74.12	62.09	48.47	53.51	52.46	51.48	63.77	60.31	90.00	71.36	56.83	42.30	90.00	63.04
'H77/29-2×96AC 93'	53.14	46.57	67.02	55.58	45.14	52.95	51.02	49.71	56.12	48.56	90.00	64.89	46.13	36.03	90.00	57.39
'H77/29-2×Togo II'	58.27	55.94	66.51	60.24	50.72	52.79	52.71	52.07	65.63	53.71	90.00	69.78	57.63	46.52	90.00	64.72
'H77/29-2×99HS- 18'	57.41	46.38	79.18	60.99	48.47	50.24	50.21	49.64	61.79	56.03	90.00	69.27	48.82	37.25	90.00	58.69
'G73-107×77/245'	51.15	46.46	61.03	52.88	49.77	52.42	54.50	52.23	70.06	60.63	90.00	73.56	56.85	45.94	90.00	64.26
'G73-107×CVJ 2-5-3-1-3'	51.34	48.94	64.27	54.85	49.01	53.17	51.81	51.33	66.37	61.24	90.00	72.54	52.53	47.10	90.00	63.21
'G73-107×1305'	48.81	45.61	75.97	56.80	47.17	47.91	47.75	47.61	67.04	63.80	90.00	73.61	45.56	41.15	90.00	58.90
'G73-107×(77/371× BSECT CP 1)'	56.36	55.19	62.83	58.12	49.86	52.19	52.03	51.36	79.90	62.03	90.00	77.31	66.20	54.36	90.00	70.19
'G73-107×96AC 93'	57.40	45.10	64.15	55.55	51.29	49.82	51.95	51.02	69.78	55.56	90.00	71.78	61.56	40.19	90.00	63.92
'G73-107×Togo II'	44.60	43.57	60.44	49.53	43.96	51.38	49.51	48.29	52.79	48.35	90.00	63.71	40.18	36.03	90.00	55.40
'G73-107×99HS 18'	54.73	43.56	63.74	54.01	51.02	49.55	50.55	50.37	64.60	51.97	90.00	68.86	55.34	37.04	90.00	60.79
'77/245×CVJ 2-5-3-1-3'	47.66	46.66	59.21	51.17	51.70	49.18	49.00	49.96	59.28	58.59	90.00	69.29	47.85	46.13	90.00	61.33
'77/245×1305'	45.75	40.60	60.52	48.95	51.28	52.97	52.03	52.10	51.02	49.90	90.00	63.64	39.79	34.64	90.00	54.81
'77/245×(77/371× BSECT CP 1)'	50.17	49.29	60.22	53.22	51.08	54.73	52.74	52.85	53.08	50.44	90.00	64.51	44.98	41.91	90.00	58.96
'77/245×96AC 93'	54.72	47.05	62.21	54.66	51.35	51.97	50.06	51.13	52.47	48.43	90.00	63.63	47.08	37.84	90.00	58.31
'77/245×Togo II'	52.52	44.92	58.89	52.11	51.88	48.61	50.74	50.41	48.85	42.63	90.00	60.49	44.21	33.79	90.00	56.00
'77/245×99HS 18'	57.40	40.99	68.72	55.70	52.49	48.98	52.58	51.35	56.28	46.16	90.00	64.15	48.63	30.14	90.00	56.26
'CVJ 2-5-3-1-3×1305'	43.64	39.44	57.00	46.69	49.74	45.17	46.50	47.14	60.97	55.79	90.00	68.92	45.94	38.42	90.00	58.12
'CVJ 2-5-3-1-3× (77/371 ×BSECT CP-1)'	43.45	38.08	67.74	49.76	52.72	49.96	50.35	51.01	66.50	57.66	90.00	71.39	42.88	33.81	90.00	55.56
'CVJ 2-5-3-1-3×96AC 93'	48.62	41.97	57.43	49.34	48.84	49.80	50.58	49.74	74.77	67.60	90.00	77.45	59.57	47.09	90.00	65.55
'CVJ 2-5-3-1-3×Togo II'	46.70	43.43	62.33	50.82	43.99	48.13	46.31	46.14	58.06	66.14	90.00	71.40	44.22	44.79	90.00	59.67
'CVJ 2-5-3-1-3×99HS 18'	54.93	50.80	72.73	59.49	52.76	49.84	51.62	51.41	73.22	65.90	90.00	76.37	55.34	47.66	90.00	64.33
'1305×(77/371×BSECT	46.13	45.39	57.17	49.56	49.86	49.55	50.80	50.07	51.37	48.70	90.00	63.36	42.10	39.36	90.00	57.15

* Transformed data

(Contd…)

Genotype	Germination (%)				Rate of emergence*				STI* (%)				SSTI* (%)			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
CP 1)'																
'1305×96AC 93'	54.73	51.77	68.30	58.27	52.24	47.79	49.19	49.74	71.17	69.65	90.00	76.94	56.40	52.20	90.00	66.20
'1305×Togo II'	42.30	34.20	52.62	43.04	43.09	45.61	44.45	44.38	57.81	43.73	90.00	63.85	45.75	28.87	90.00	54.87
'1305×99HS 18'	54.33	45.07	69.47	56.29	52.25	47.53	49.91	49.89	72.87	69.68	90.00	77.52	55.76	44.79	90.00	63.52
'(77/371×BSECT CP-1)×96AC 93'	55.95	44.29	74.61	58.28	52.16	49.55	51.21	50.97	70.87	63.68	90.00	74.85	54.32	40.38	90.00	61.57
'(77/371×BSECT CP-1)×Togo II'	52.52	47.28	61.06	53.62	54.92	48.08	51.32	51.44	80.25	75.05	90.00	81.77	63.10	54.13	90.00	69.08
'(77/371×BSECT CP 1) ×99HS 18'	55.95	42.98	62.95	53.96	47.29	48.87	50.31	48.83	73.66	69.45	90.00	77.70	63.12	45.56	90.00	66.23
'96AC 93×Togo II'	50.17	39.77	64.86	51.60	50.19	51.95	52.37	51.50	59.22	54.86	90.00	68.03	46.89	34.84	90.00	57.24
'96AC 93×99HS 18'	55.95	48.12	69.24	57.77	50.36	53.85	52.05	52.09	74.11	53.78	90.00	72.63	58.73	39.79	90.00	62.84
'Togo II×99HS 18'	46.70	44.97	72.93	54.87	47.18	43.19	47.96	46.11	56.88	54.31	90.00	67.06	39.80	36.65	90.00	55.48
Mean	50.43	44.82	62.71	52.65	47.92	49.81	49.23	48.99	63.77	58.41	90.00	70.72	50.79	41.90	90.00	60.90
CD (*P*=0.05)	2.72	2.96	4.53		5.97	5.37	5.34		5.55	5.25			4.21	4.09		
SE (d)	1.37	1.49	2.28		3.01	2.70	2.69		2.79	2.64			2.12	2.06		
SE (m)	0.97	1.06	1.61		2.13	1.91	1.90		1.98	1.87			1.49	1.46		
CV (%)	3.32	4.08	4.46		7.69	6.65	6.69		5.37	5.55			5.11	6.02		

Genotype	No. of leaves/seedling				Seedling height (cm)				Fresh weight (g)/seedling				Dry weight (g)/seedling			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
'H77/833-2'	6.61	5.02	8.00	6.54	9.08	7.85	22.45	13.13	8.59	15.37	19.24	14.40	1.54	1.43	1.60	1.52
'H77/29-2'	3.63	2.94	4.27	3.61	11.25	11.75	17.89	13.63	3.17	24.00	28.11	18.43	0.93	1.91	2.52	1.79
'G73-107'	8.78	7.10	9.35	8.41	11.66	14.75	19.66	15.36	9.43	17.44	49.45	25.44	1.43	1.29	3.66	2.13
'77/245'	3.77	2.92	4.37	3.69	14.38	13.73	20.85	16.32	6.07	18.63	59.57	28.09	1.17	1.80	5.09	2.69
'CVJ 2-5-3-1-3'	8.02	5.80	9.23	7.68	12.14	14.37	18.07	14.86	11.63	16.10	41.66	23.13	1.71	1.41	4.07	2.40
'1305'	3.50	2.84	4.14	3.49	8.58	11.37	17.37	12.44	5.40	9.67	48.61	21.23	1.25	0.88	4.17	2.10
'77/371×BSECT CP 1'	6.21	5.42	7.00	6.21	13.77	14.87	18.92	15.85	9.28	26.60	33.30	23.06	1.50	2.58	3.01	2.36
'96AC-93'	7.01	5.90	8.99	7.30	13.03	12.59	18.52	14.71	10.56	14.45	59.72	28.25	1.85	1.47	5.86	3.06
'Togo II'	6.81	6.29	8.53	7.21	10.56	12.20	22.72	15.16	9.24	14.66	91.13	38.34	1.46	1.29	8.83	3.86
'99HS 18'	7.45	5.54	9.15	7.38	12.77	10.75	18.08	13.87	12.41	28.33	70.70	37.15	2.28	2.26	6.15	3.56
'H77/833-2×H77/29-2'	7.11	5.85	7.80	6.92	14.32	14.98	22.33	17.21	13.50	44.05	83.73	47.09	1.59	4.99	7.82	4.80
'H77/833-2×G73-107'	11.01	7.05	13.40	10.49	16.75	16.35	22.05	18.38	12.36	32.11	57.89	34.12	1.34	3.13	5.47	3.31
'H77/833-2×77/245'	7.40	5.25	9.65	7.44	15.77	15.22	22.63	17.87	10.58	69.33	87.19	55.70	2.55	5.53	7.82	5.30
'H77/833-2× CVJ 2-5-3-1-3'	9.98	8.85	12.58	10.47	17.91	17.57	21.65	19.04	20.21	80.30	52.76	51.09	3.54	7.79	4.77	5.37
'H77/833-2×1305'	11.92	9.34	16.00	12.42	17.00	18.42	28.41	21.28	14.27	62.28	91.34	55.96	5.70	5.79	8.13	6.54
'H77/833-2×(77/371 ×BSECT CP 1)'	8.98	7.26	15.25	10.50	14.53	15.15	31.20	20.29	7.89	46.55	104.28	52.91	2.11	4.08	8.58	4.92
'H77/833-2×96AC 93'	11.07	8.73	11.93	10.58	18.35	17.83	24.27	20.15	25.32	66.49	161.06	84.29	3.50	6.50	14.73	8.24
'H77/833-2×Togo II'	9.79	6.70	11.07	9.19	15.64	15.63	25.00	18.76	18.82	47.72	116.60	61.05	2.96	4.69	9.72	5.79
'H77/833-2×99HS 18'	9.78	7.33	11.35	9.49	15.93	18.00	20.49	18.14	15.71	48.02	140.24	67.99	2.03	5.44	15.47	7.65
'H77/29-2×G73-107'	10.00	7.20	13.63	10.28	14.95	15.68	20.75	17.13	9.59	51.57	85.17	48.77	2.18	3.82	6.66	4.22
'H77/29-2×77/245'	8.80	6.20	8.97	7.99	15.57	15.37	26.13	19.02	18.51	57.56	57.29	44.45	3.66	5.62	5.24	4.84
'H77/29-2×CVJ 2-5-3-1-3'	9.81	9.32	14.51	11.21	18.44	20.33	28.93	22.57	16.51	80.61	148.85	81.99	2.64	5.97	10.54	6.38
'H77/29-2×1305'	9.26	7.25	14.97	10.49	13.25	16.77	30.99	20.34	17.56	72.43	140.48	76.82	3.18	6.35	12.32	7.28
'H77/29-2×(77/371× BSECT CP 1)'	9.77	6.71	13.80	10.09	19.58	18.87	31.05	23.17	11.18	46.75	144.11	67.34	2.42	4.57	13.18	6.72
'H77/29-2×96AC 93'	8.46	6.79	13.97	9.74	15.12	17.17	27.79	20.02	26.68	44.08	113.93	61.56	3.56	5.00	12.11	6.89
'H77/29-2×Togo II'	8.73	7.19	10.40	8.77	15.19	17.38	21.59	18.05	24.37	98.67	161.62	94.89	3.61	9.61	15.27	9.50
'H77/29-2×99HS 18'	10.12	7.30	16.00	11.14	19.38	17.87	31.51	22.92	15.74	62.18	113.18	63.70	2.90	6.06	9.56	6.17
'G73-107×77/245'	10.21	7.90	12.92	10.34	18.56	18.13	22.10	19.60	24.35	85.50	78.28	62.71	3.38	6.33	6.12	5.28
'G73-107×CVJ 2-5-3-1-3'	10.39	8.63	12.54	10.52	15.17	17.69	24.07	18.97	15.56	77.28	91.36	61.40	2.39	8.76	9.17	6.77

(Contd…)

(concluded Table 1)

Genotype	No. of leaves/seedling				Seedling height (cm)				Fresh weight (g)/seedling				Dry weight (g)/seedling			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
'G73-107×1305'	11.40	8.82	16.57	12.26	12.17	15.07	28.32	18.52	17.77	51.89	111.49	60.38	2.89	5.88	11.97	6.91
'G73-107×(77/371× BSECT CP 1)'	9.77	7.03	13.95	10.25	18.55	19.46	27.30	21.77	18.01	34.82	104.15	52.33	2.39	2.77	7.53	4.23
G73-107×96AC 93	10.77	8.60	12.64	10.67	17.18	18.40	28.61	21.40	13.45	93.33	146.69	84.49	2.97	8.45	12.78	8.07
'G73-107×Togo II'	9.06	8.81	11.89	9.92	16.80	18.08	30.87	21.92	11.12	46.78	93.19	50.36	1.86	4.73	9.85	5.48
'G73-107×99HS 18'	11.71	7.66	16.35	11.91	13.98	16.75	33.70	21.48	27.53	86.72	119.18	77.81	3.62	6.91	9.81	6.78
'77/245×CVJ 2-5-3-1-3'	9.84	9.20	11.94	10.33	15.00	17.28	22.03	18.10	22.82	46.79	114.92	61.51	3.28	4.24	11.16	6.23
'77/245×1305'	12.79	8.23	15.50	12.17	14.38	15.77	20.80	16.98	9.49	104.39	120.53	78.14	1.21	9.15	9.92	6.76
'77/245×(77/371× BSECT CP 1)'	8.33	5.88	9.39	7.87	15.05	16.97	28.46	20.16	32.22	85.18	126.21	81.20	4.69	8.27	11.41	8.12
'77/245×96AC 93'	7.95	6.62	10.58	8.38	16.53	17.97	21.17	18.56	19.34	60.56	115.43	65.11	3.52	5.63	9.11	6.08
'77/245×Togo II'	9.77	7.51	12.43	9.90	17.23	17.18	31.63	22.01	17.49	82.50	154.43	84.81	2.29	8.06	14.12	8.16
'77/245×99HS 18'	10.45	8.63	11.84	10.31	20.16	19.70	28.54	22.80	32.17	130.27	35.31	65.91	3.95	9.65	2.85	5.49
'CVJ 2-5-3-1-3×1305'	9.36	8.48	14.03	10.63	13.58	14.22	21.79	16.53	12.54	28.03	101.94	47.50	1.78	2.54	8.01	4.11
'CVJ 2-5-3-1-3×(77/371 ×BSECT CP-1)'	8.00	7.12	10.13	8.41	13.35	17.42	24.00	18.26	9.22	52.26	128.06	63.18	2.36	4.58	10.54	5.83
'CVJ 2-5-3-1-3×96AC 93'	9.33	7.38	14.78	10.50	15.52	16.80	32.60	21.64	16.67	100.94	119.41	79.01	2.50	9.74	11.15	7.79
'CVJ 2-5-3-1-3×Togo II'	9.63	8.55	11.80	9.99	14.22	16.07	26.38	18.89	10.12	41.63	110.61	54.12	2.61	3.77	8.91	5.10
'CVJ 2-5-3-1-3×99HS 18'	9.98	8.07	13.38	10.47	14.35	16.00	27.00	19.12	30.56	32.37	70.89	44.61	4.49	3.01	6.58	4.69
'1305×(77/371×BSECT CP-1)'	8.63	6.30	9.13	8.02	14.99	17.67	20.58	17.74	18.82	46.65	79.20	48.22	3.56	4.26	7.24	5.02
'1305×96AC 93'	8.75	6.94	14.76	10.15	16.78	16.05	27.57	20.14	15.16	100.37	119.60	78.38	3.11	11.38	12.84	9.11
'1305×Togo II'	6.37	5.66	7.94	6.66	11.77	16.80	22.49	17.02	9.02	46.76	93.88	49.89	2.41	4.56	7.95	4.97
'1305×99HS 18'	11.15	8.18	14.10	11.14	17.74	17.67	27.66	21.02	21.45	46.28	106.18	57.97	3.01	4.47	9.91	5.80
'(77/371×BSECT CP 1) ×96AC-93'	9.55	7.53	14.62	10.57	17.48	17.95	31.71	22.38	15.37	125.86	143.79	95.01	2.11	11.04	11.83	8.33
'(77/371×BSECT CP 1) ×Togo II'	8.59	6.93	9.90	8.48	19.65	20.07	26.53	22.08	21.36	56.01	95.03	57.47	3.15	6.35	10.01	6.50
'(77/371×BSECT CP 1) ×99HS 18'	9.03	6.22	11.25	8.83	15.01	16.87	27.05	19.64	19.35	72.53	118.06	69.98	3.14	7.04	10.67	6.95
'96AC 93×Togo II'	10.07	7.28	11.67	9.67	17.59	16.18	21.23	18.34	15.39	103.47	122.12	80.33	3.25	9.07	10.90	7.74
'96AC 93×99HS 18'	10.13	6.52	13.34	10.00	13.53	16.18	29.25	19.66	35.32	72.23	119.50	75.69	4.40	6.54	10.24	7.06
'Togo II×99HS 18'	9.39	6.53	14.62	10.18	11.17	12.78	25.82	16.59	34.48	67.64	119.10	73.74	4.77	7.67	12.07	8.17
Mean	8.98	7.01	11.68	9.22	15.13	16.18	24.92	18.74	16.56	57.73	98.54	57.61	2.72	5.38	8.85	5.65
CD (*P*=0.05)	1.03	1.33	1.92	%	2.84	2.05	2.76	%	2.21	4.27	8.90	%	0.38	0.40	0.79	%
SE (d)	0.52	0.67	0.96	%	1.43	1.03	1.39	%	1.11	2.15	4.48	%	0.19	0.20	0.40	%
SE (m)	0.36	0.47	0.68	%	1.01	0.73	0.98	%	0.79	1.52	3.17	%	0.14	0.14	0.28	%
CV (%)	7.05	11.74	10.12	%	11.57	7.83	6.85	%	8.24	4.566	5.57	%	8.65	0.63	5.53	%

namely, 'H77/833-2×H77/29-2', 'H77/833-2×77/245', 'H77/833-2×96AC-93', 'H77/29-2×CVJ 2-5-3-1-3', 'H77/29-2×1305', 'G73-107×77/245', 'G73-107×1305', '1305×96AC-93', '1305×99HS-18' and '(77/371×BSECT CP-1)×Togo II' showed consistency for positive significant values for STI in both the stress environments (E_1 and E_2). The cross '(77/371×BSECT CP-1)×Togo II' was the best specific combination (13.925) for STI in E_1 but in E_2 the cross 'H77/29-2×1305' showed the highest SCA value (19.245) while the cross combination 'H77/833-2×1305' was identified as the poorest specific cross combination for STI in both the stress environments (E_1 and E_2).

As regards the SCA effects for SSTI (Table 3) the results were almost similar to STI. In both the environments (E_1 and E_2) 10 cross combinations, ie 'H77/833-2×H77/29-2', 'H77/833-2×(77/371×BSECT CP-1)', 'H77/833-2×96AC-93', 'H77/29-2×CVJ 2-5-3-1-3', 'H77/29-2×Togo II', 'G73-107×77/245', 'G73-107×(77/371×BSECT CP 1)', '1305×96AC 93', '1305×99HS 18' and '(77/371× BSECT CP 1) × Togo II' were identified as the crosses having the positive significant SCA values for SSTI. The cross '1305×99HS 18' was the best specific combination (11.204) followed by the cross 'H77/833-2×96AC 93' as close runner up with a value (11.088) in E_1 but in E_2 the cross 'H77/833-2×96AC-93' showed the highest SCA value (18.303) followed by the cross '1305×96AC 93' as close runner up with a value (15.162). While the cross 'H77/833-2×1305' was identified as the poorest specific cross combination for SSTI in both the environments (E_1 and E_2). The best specific cross '1305×99HS 18' involves the one susceptible parent,

Table 2 Estimates of GCA and SCA effects for seedling thermo-tolerance index (STI)

Parent	H77/833-2	H77/29-2	G73-107	77/245	CVJ 2-5-3-1-3	1305	77/371× BSECT CP 1	96AC 93	Togo II	99HS 18
H77/833-2		3.84*	3.18	7.75**	–0.31	–22.07**	–1.00	8.20**	–3.67	–12.39**
		3.64*	6.07**	8.29**	–3.14	–23.61**	–1.10	14.11**	–6.32**	–13.37**
H77/29-2			–1.82	3.07	10.90**	10.09**	–1.17	–8.14**	5.92**	–2.74
			–1.84	2.56	17.18**	19.24**	–0.85	–10.41**	–2.85	–3.31
G73-107				12.47**	–3.62	8.57**	10.02**	0.58	–8.43**	–4.86*
				11.22**	–2.56	12.06**	0.63	–3.64*	–11.85**	–7.59**
77/245					–0.10	3.15	–6.19**	–6.11**	–5.18*	–2.58
					2.47	5.85**	–3.27	–3.09	–6.48**	–5.73**
CVJ 2-5-3-1-3						0.70	–5.18*	3.77*	–8.37**	1.95
						–2.64	–10.44**	1.67	2.62	–0.38
1305							–8.77**	11.70**	2.89–	13.13**
							–7.34**	15.79**	7.70**	15.46**
77/371×BSECT CP 1								–0.02	13.92**	2.50
								0.16	13.94**	5.56**
96AC 93									–6.42**	3.63–
									–4.05*	7.91**
Togo II										–9.03**
										–4.96*
99HS 18										
GCA effects	3.14**	–2.72**	2.21**	–8.39**	4.01**	–7.51**	3.90**	3.21**	–1.34*	3.48**
	3.87**	–0.88	–0.66	–8.34**	6.05**	–6.01**	3.64**	1.45*	–0.95	1.82**

†Upper values for E_1 and lower values for E_2; *P = 0.05, **P = 0.01

'1305'. This parent also gave best specific cross for STI. It is a re-assertion of the fact the heat tolerant genes are also contributed by parents with poor performance per-se. This indicates a complex nature of gene distribution and the control system for the trait. The contribution of positive genes by the poor performer has a special significance in plant breeding. We can expect the genes being disbursed in large germplasm and coming from any parent. This would also suggest that in absence of particular sources, the trait could be tested in hybrids as a qualifying standard.

Of the 10 F_1 hybrids each for STI and SSTI showing significant and positive SCA-effects, eight hybrids for STI and five hybrids for SSTI involved one of the parents having high GCA-effect while the other parent had low GCA-effect for the trait. This indicated that diversity in parental GCA effects played an important role for the production of hybrids with significant positive SCA-effects for STI and SSTI in pearl millet. The diversity in parental GCA-effects was necessary for the development of specific combinations with high value. This kind of superiority of high × low crosses might involve dominant × recessive type of gene interaction and, therefore, might tend to be unfixable. Crosses involving at least one parent with high GCA-effect could produce good segregates, only if, the additive genetic system present in the good general combiner and the complementary epistatic effects in the other act in the same direction to maximize the desirable plant attribute (Chotaliya *et al*. 2010).

Remaining, one out of the two for STI and five for SSTI F_1 crosses having significant and positive SCA-effects involved both the parents with high GCA-effects for STI and SSTI. Superiority of such hybrid might be due to additive and additive × additive type of interaction, which is fixable. Therefore, more heat-tolerant genotypes could be obtained in the segregating generations of these crosses. In such a situation the estimation of GCA and SCA assume added significance. Pure additive action at individual loci was coupled with favourable additive × additive interaction could produce heterotic combinations. Also, the heterosis was related to GCA of parents and SCA of crosses. Therefore, superior recombinants with high STI and SSTI could be isolated from these crosses as these involved both the parents with high GCA effects, although the chances would depend on linkage relationship. It was a matter of enormous importance that the best specific cross 'H77/29-2×1305' had resulted from the two susceptible parents. That would mean the genes for heat tolerance are distributed across the parents.

The estimate of general combining ability (GCA) effects in respect of germination (%) indicated that parents 'H77/29-2' and '(77/371×BSECT CP-1)' exhibited significant positive GCA effects in all the three environments. The parent 'G73-107' showed positive GCA effect in both the stress environments (E_1 and E_2). A consideration of specific combining ability (SCA) effects reveals that out of 45 cross combinations only five crosses, namely, 'H77/833-2×H77/

Table 3 Estimates of GCA and SCA effects for seed to seedling thermo-tolerance index (SSTI)

Parent	H77/833-2	H77/29-2	G73-107	77/245	CVJ 2-5-3-1-3	1305	77/371× BSECT CP 1	96AC 93	Togo II	99HS 18
H77/833-2		6.22**	5.13**	0.24	3.87*	–16.00**	6.92**	11.08**	1.14–	–4.49**
		6.57**	0.32	0.64	–0.81	–17.49**	9.81**	18.30**	8.78**	–0.79
H77/29-2			0.92–	2.55	9.23**	–1.16	2.48	–8.62**	6.83**	–3.94*
			0.36	4.17**	10.12**	7.63**	–4.22**	–7.76**	4.79**	–4.41**
G73-107				7.58**	–1.96	–0.71	9.04**	3.99*	–13.43**	–0.23
				6.19**	–0.04	3.14*	7.36**	–4.08**	–6.15**	–5.08**
77/245					1.37	1.53	–4.15**	–2.45	–1.36	1.08
					4.47**	2.13	0.41	–0.93	–2.902*	–6.50**
CVJ 2-5-3-1-3						2.45	–11.49**	4.79**	–6.60**	2.55
						–1.48	–15.09**	0.91	0.69	3.63*
1305							–4.04**	9.85**	3.15*	11.20**
							–0.40	15.16**	–6.08**	9.89**
77/37×BSECT CP 1								–3.11*	9.62**	7.68**
								–5.64	10.18**	1.67
96AC 93									–6.98**	2.87*
									–6.37**	–1.37
Togo II										–12.09**
99HS 18										–2.43
GCA effects	0.63	0.44	3.25**	–4.77**	0.46	–7.76**	3.12**	3.52**	–0.42	1.53**
	1.65**	1.19*	1.66**	–3.82**	3.57**	–5.56**	3.42**	0.69	–1.38**	–1.44**

†Upper values for E_1 and lower values for E_2; * *P* = 0.05; ** *P* = 0.01

29-2', 'H77/29-2×Togo II', 'CVJ 2-5-3-1-3×99HS 18', '1305×96AC 93' and '1305×99HS 18' exhibited significant positive SCA effects in all the three environments. The crosses 'H77/833-2×(77/371×BSECT CP 1)', 'H77/833-2×96AC 93', 'H77/29-2×CVJ 2-5-3-1-3', 'G73 107× (77/371×BSECT CP 1)' and '(77/371×BSECT CP-1)×Togo II' showed significant and positive SCA effects in stress environments (E_1 and E_2).

The parent '(77/371×BSECT CP 1)' was found to be the best general combiner for emergence rate (ER). Significant positive SCA effects in all the three environments for this trait were exhibited by only one cross combination, namely, 'H77/29-2×G73-107'. However, the cross 'H77/833-2×G73-107' in E_1 and E_2 showed consistency for positive significant values in two environments.

For number of leaves/seedling positive and significant GCA effects were recorded for the parents 'G73-107' and 'CVJ 2-5-3-1-3' in all the three environments (E_1, E_2 and E_3). These parents could, therefore be termed as overall best combiners for number of leaves/seedling. Six cross combinations, namely, 'H77/833-2×1305', 'H77/29-2×CVJ 2-5-3-1-3', 'H77/29-2×1305', 'G73-107×1305', '77/245×1305' and '77/245×Togo-II' showed consistency for positive significant SCA values in all the three environments (E_1, E_2 and E_3). Three crosses, namely, 'H77/833-2×96AC-93', '77/245×CVJ 2-5-3-1-3' and '1305×99HS 18' exhibited significant and positive SCA effects in both the stress environments (E_1 and E_2).

Only 1 parent, ie '(77/371×BSECT CP 1)' showed the consistency for significant positive GCA effects for seedling height and hence, was the best general combiner for this trait (Table 4). The seven cross combinations, namely 'H77/833-2×1305', 'H77/29-2×CVJ 2-5-3-1-3', 'H77/29-2×(77/371×BSECT CP-1)', 'H77/29-2×99HS 18', 'G73-107×Togo II', '77/245×99HS 18' and '1305×99HS 18' showed significant positive SCA effects consistently over all the 3 environments. The 4 crosses, namely 'H77/833-2×CVJ 2-5-3-1-3', 'H77/833-2×96AC 93', 'G73-107×(77/371×BSECT CP-1)' and '(77/371×BSECT CP-1)×Togo II' in both the stress environments (E_1 and E_2) showed the consistency over the two environments for the positive significant SCA values.

The parent '96AC 93' appeared to be good general combiner for seedling fresh weight (g) having significant positive GCA effect in all the environments (E_1, E_2 and E_3), while, the parents '77/245' and '99HS 18' showed the positive significant GCA values in stress environments (E_1 and E_2). A consideration of SCA effect reveals that out of 45 cross combinations ten crosses, namely, 'H77/833-2×1305', 'H77/833-2×96AC 93', 'H77/29-2×CVJ 2-5-3-1-3', 'H77/29-2×1305', 'H77/29-2×Togo II', 'G73-107×99HS 18', '77/245×(77/371×BSECT CP-1)' and 'Togo II×99HS 18' exhibited significant positive SCA effects in all the three environments. The crosses, ie 'H77/833-2×CVJ 2-5-3-1-3', 'G73-107×77/245' and '77/245×99HS-18' showed significant and positive SCA effects in stress environments (E_1 and E_2).

For dry weight (g)/seedling the parent '96AC 93' was identified as the best general combiner over all the three environments and '99HS 18' in stress environments (E_1 and E_2) having highest positive GCA effect. Significant positive SCA effects in all the three environments for dry weight (g)/ seedling were exhibited by eight cross combinations, namely, 'H77/833-2×96AC 93', 'H77/29-2×1305', 'H77/29-2×Togo II', 'G73-107×1305', 'G73-107×96AC-93', 'G73-107×99HS 18', '77/245×(77/371×BSECT CP 1)' and 'Togo II×99HS 18'. However, six crosses, namely, 'H77/833-2×CVJ 2-5-3-1-3', 'H77/833-2×1305', 'G73-107×77/245', '77/245×99HS 18', '(77/371×BSECT CP 1)×Togo II' and '96AC 93×Togo II' in both the stress environments (E_1 and E_2), showed consistency for positive significant SCA effects in two environments.

Estimates of the GCA-effects of 10 parental genotypes for eight characters revealed that none of the parents had good general combining ability for all the traits studied. Therefore, to determine the best combiner across the characters, each parent was given a score for each trait based on their GCA-effects. A score of '+1' was assigned for significant GCA-effect in desirable direction, while '-1' for significant GCA-effect in undesirable direction. A score of '0' was assigned for non-significant GCA-effect (Banerjee and Kole 2009). The scores revealed that '96AC 93' appeared as best overall general combiner in all the three environments (total score 6, 3 and 4, respectively) and the parent '99HS 18' (total score 6, 1 and 3, respectively) as the first runner up. In addition, '77/371×BSECT CP 1' in E_1, E_2 and E_3 (2, 1 and 3, respectively), 'G73-107' in both the stress environments E_1, E_2 (2, and 2, respectively) following 'CVJ 2-5-3-1-3' in both the stress environments E_1, E_2 (2, and 1,

Table 4 Genetic component (fixed effect model) for different characters

Genetic component	STI (%)	SSTI (%)	Germination (%)	Emergence rate	Leaves/ seedling	Seedling height (cm)	Fresh weight (g) / seedling	Dry weight (g) /seedling
σ^2 g (GCA var)	22.42	13.05	7.71	2.85	0.31	0.40	6.97	0.06
	19.53	8.88	5.02	0.62	0.21	0.32	49.66	0.39
			6.76	1.64	0.66	0.53	83.43	0.90
σ^2 s (SCA var)	64.94	48.69	24.24	20.44	3.48	6.22	51.45	1.10
	90.44	52.42	26.58	5.40	1.87	5.63	908.81	7.74
			31.08	11.07	9.09	21.35	1336.00	11.51
σ^2 e (environmental var)	3.9	2.24	0.93	4.52	0.13	1.02	0.62	0.01
	13.49	2.11	1.11	3.65	0.22	0.53	2.31	0.02
			2.60	3.61	0.46	0.97	10.06	0.08
σ^2 A (additive var)	44.8	26.10	15.42	5.71	0.63	0.80	13.95	0.12
	439.06	17.77	10.05	1.25	0.43	0.65	99.32	0.78
			13.53	3.29	1.32	1.06	166.87	1.80
σ^2 D (dominance var)	64.94	48.69	24.24	20.44	3.48	6.22	51.45	1.10
	90.44	52.42	26.58	5.40	1.87	5.63	908.81	7.74
			31.08	11.07	9.09	21.35	1336.00	11.51
σ^2 p (phenotypic var)	113.70	77.05	40.60	30.67	4.24	8.05	66.03	1.25
	133.00	72.31	37.75	10.31	2.52	6.81	1010.45	8.54
			47.23	17.98	10.88	23.38	1512.94	13.40
h^2_{ns} (narrow Sense)	0.39	0.33	0.37	0.18	0.14	0.10	0.21	0.09
	0.29	0.24	0.26	0.12	0.17	0.09	0.09	0.09
			0.28	0.18	0.12	0.04	0.11	0.13
h^2_{bs} (broad Sense)	0.96	0.97	0.97	0.85	0.96	0.87	0.99	0.98
	0.97	0.97	0.97	0.64	0.91	0.92	0.99	0.99
			0.94	0.79	0.95	0.95	0.99	0.99
GCA / SCA ratio	0.34	0.26	0.31	0.13	0.09	0.06	0.13	0.05
	0.21	0.16	0.18	0.11	0.11	0.05	0.05	0.05
			0.21	0.14	0.07	0.02	0.06	0.07
Predictability factor	0.40	0.34	0.38	0.21	0.15	0.11	0.21	0.10
	0.30	0.25	0.27	0.18	0.18	0.10	0.09	0.09
			0.30	0.22	0.12	0.04	0.11	0.13

†Upper values for E_1, middle values for E_2 and lower values for E_3

respectively) appeared to be overall good general combiners, while, '1305' was the poorest overall general combiner in all the three environments (-6, -6 and -3, respectively). However, for selection of parents, involvement of genetic and environmental correlations as well as indices for various traits might be considered.

Nature of gene action

The relative magnitudes of the respective variances for GCA and SCA (Table 4), however, showed that the later was more important for the characters, such as, seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER), number of leaves/seedling, seedling height, seedling fresh weight (g) and seedling dry weight (g) indicating that non-additive genetic variance (dominance variance) was mainly responsible in the inheritance of these characters. The preponderance of non-additive interaction as seen in this analysis is also some times caused due to presence of epistasis and / or a correlated gene distribution. A further bias may also be caused due to interaction of non-additive variance with the environment.

Realizing that individual components of genetic variance also interact with environment and can thus be biased, it becomes important to evaluate these interactions also. Both the additive and dominance components can interact with changes in the environment.

Predictability factor calculated from GCA and SCA variances reflects the degree to which character is transmitted to the progeny. The closer is the ratio to unity, the greater is the predictability of progeny performance based on the GCA-effect. Higher the involvement of additive gene actions in the inheritance of character, better will be the transmission of the trait to the progeny (Banerjee and Kole 2009).

The nature of genetic variance could be revealed by studying the s2GCA/s2SCA ratio. This ratio was low for all the characters, ie seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER), number of leaves/seedling, seedling height (cm), seedling fresh weight (g), seedling dry weight (g) in all the three environments, the low ratio as well as the higher magnitude of dominance component of variance than additive variance would confirm that most characters were predominantly under the control of non-additive genetic variance. The additive and dominance components were calculated and used for the estimation of heritability in broad sense as well as narrow sense.

The magnitude of dominance component of variance (s2D) was higher than that of the additive component of variance (s2A) for seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER), number of leaves/seedling, seedling height, seedling fresh weight (g), seedling dry weight (g) indicating that these characters were mainly under the control of dominance component of variance. This should facilitate the success of hybrid breeding by making use of the expected heterosis. The heterosis breeding has been the hallmark of genetic improvement of pearl millet for grain productivity and other traits. The results in this investigation suggest that hybrid breeding could probably hold true for thermo-tolerance too. The estimates of additive genetic variance and narrow sense heritability for STI and SSTI were of moderate magnitude which also indicated good chances of effective selection. The values of broad sense heritability (h^2bs) for most other characters were quite high. This would be of little significance or for the fixation of genes is concerned, but would certainly suggest the adoption of heterotic breeding as a method. The analysis of genetic components overwhelmingly supported the method of hybrid breeding as the principal approach for genetic improvement in pearl millet.

Correlation

While evaluating the diallel progenies the pooled correlations among the traits as given in Table 5, were calculated with a view to find whether there was any

Table 5 Pooled correlation coefficient among various characters in all the three environments

Character	Germination (%)	Rate of emergence	STI (%)	SSTI (%)	No. of leaves/ seedling	Seedling height (cm)	Fresh weight (g) /seedling	Dry weight (g) /seedling
Germination (%)	1.00	0.35**	0.35**	0.59**	0.23	0.37**	0.29*	0.26
Rate of emergence		1.00	0.23	0.35**	0.60**	0.58**	0.55**	0.52**
STI (%)			1.00	0.83**	0.24	0.12	0.08	0.04
SSTI (%)				1.00	0.23	0.26	0.18	0.14
No. of leaves/ seedling					1.00	0.68**	0.63**	0.60**
Seedling height (cm)						1.00	0.70**	0.66**
Fresh weight (g) /seedling							1.00	0.95**
Dry weight (g) /seedling								1.00

*P = 0.05
**P = 0.01

association of these traits with tolerance indices. Seedling thermo-tolerance index (STI) had a significant positive association with germination (%) and seed to seedling thermo-tolerance index (SSTI). SSTI, in addition, was also positively correlated with germination (%), emergence rate and STI. It was seen that the heat tolerance indices STI and SSTI were not showing any perceptible pooled correlation with rest of the developmental traits. Since, experiment proceeded without any stress after the establishment of seedling (Peacock *et al*. 1993), the pearl millet plants show great resilience and recovery. Hence the early heat effects could have no impact on its later growth and development (Yadav *et al*. 2006).

The nature and magnitude of gene action which was predominantly non-additive type for the expression of the supra-optimal temperature tolerance indices (STI and SSTI) and related seedling traits, viz germination (%), emergence rate (ER), number of leaves/seedling, seedling height, seedling fresh weight (g), seedling dry weight (g) in all the three environments (two stress and one normal) indicated that hybrid breeding might be effective for improvement of such traits. However, the estimates of additive genetic variance and narrow sense heritability for STI and SSTI also indicated good chances of effective selection.

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