Thus, the interaction of applied fertilizer with available soil moisture through deep placement management strategy improved the spikelet number and weight. Improvement in yield components increased the grain yield and in turn the agronomic nitrogen use efficiency. Annual and seasonal rainfall which replenish the stored soil moisture could be utilized efficiently through proper N management intervention. The hypothesis that the improved water use efficiency in a rainfed *rabi* environment characterized by receding stored soil moisture can be brought about by deep placement of N fertilizer in *rabi* sorghum was validated.

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Can cold tolerance bring in hybrids on commercial front in winter sorghum?

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Studies on early-season and mid-season cold temperature stress on growth and yield components in diverse classes of winter sorghum are essential for targeting hybrid development that is otherwise confined only to rainy season-grown sorghum. The results showed that from among the 194 winter sorghum genotypes belonging to 5 groups – varieties, B-lines, R-lines, hybrids and germplasm lines, 81% of the genotypes were correctly placed in their respective groups based on discriminant analysis. Principal component analysis showed that most of the traits involved in the study are important and variability cannot be explained by a few traits and the traits recorded at seedling and maturity stages were explained by different principal components. Most of the traits recorded under cold stress at seedling stage did not correlate with those recorded under cold stress at anthesis. There is scope for improvement of individual groups for seedling dry fodder yield and grain yield, more so in the case of hybrids and female parental lines. Breeding for cold tolerance at seedling as well as anthesis stages has to be separately targeted. Thus, for developing new winter sorghum hybrids, female parental lines have to be diversified and improved for grain yield and percentage of seed set by crossing with promising germplasm lines identified in the study.

Keywords: Cold tolerance, germplasm, hybrids, winter sorghum.

SORGHUM is the fifth important cereal crop grown across the world for diverse uses – such as food, feed, fodder, fuel and fibre crop. Due to its African origin, the crop has adapted to hot and dry ecologies; however, due to gradual introduction to semi-arid tropics and temperate regions across the world, it has developed variants to suit new ecologies[1]. Due to its inherent ability to adapt to a wide range of climatic conditions, sorghum occupies a special niche in the current scenario of rapid climate change. However, being a crop of the tropics, it is considered as a cold susceptible species, though cold-tolerant germplasm has been identified. It suffers from chilling injury during the seedling stage and poor seed set during the reproductive stage when exposed to temperatures below 15°C. Cold temperature at flowering seems to be more detrimental to the yield of sorghum. All yield components, including panicle weight, number of seeds per panicle, grain yield and seed size are severely affected by mid-season cold stress[2].

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India is the largest producer of sorghum in the world. The crop grown in rainy and post-rainy seasons in India, with cultivars specific to the season of cultivation. Post-rainy season sorghum grown in winter occupies a special place catering to the food and fodder needs unlike the rainy season sorghum which is mostly damaged due to grain mould infection prevailing during the season. It is a known fact that adoption of hybrid technology is mainly restricted to sorghum grown in the rainy season, while the post-rainy sorghum tract is dominated with land-races. One reason for the failure of hybrids during winter season is the poor seed set experienced by them when the night temperature falls below 15°C. Profuse tillering is also observed in seedlings when the plants experience low temperature at the seedling stage. Though several studies were carried out independently on seedling cold tolerance and a few on cold tolerance at anthesis, the relationship between the two under natural screening has not been studied. Also, establishment of a strong relationship between seedling cold tolerance and anthesis cold tolerance would facilitate the rapid screening of a large number of germplasm lines for identification of cold tolerant sources. Sorghum germplasm with tolerance to cold at seedling stage has been reported earlier[3,4]. Stress imposed at seedling stage under controlled conditions did not affect yield parameters, though a delay in maturity was observed[1]. However stress at flowering stage was detrimental to yield[1]. However, the study[1] did not include breeding groups, especially hybrids, the commercially important breeding group. Cold-tolerant lines produced higher number of seeds under self- and open-pollinated conditions than cold-susceptible lines[5]. Keeping this in view, a study was taken up to determine the effect of early-season stress on growth components, and mid-season cold temperature stress on yield components in diverse classes of sorghum, and derive the relationship between traits recorded at the two stages. The second objective was to identify sorghum germplasm accessions tolerant to early- and mid-season cold temperature stress, that can serve as sources of cold tolerance for use in breeding programmes.

The study was conducted under field conditions at two different locations in India. Experiment I examined the effect of cold temperature stress imposed at the seedling stage, while experiment II dealt with similar stress enforced during the flowering stage. The first experiment was laid out at Mahabaleshwar, Maharashtra (India) and the second experiment was conducted at the Indian Institute of Millets Research (IIMR), Hyderabad during the 2012–2013 post-rainy season. The temperature treatments were applied by manipulating the planting dates. The cold treatment was imposed through normal-season planting (19 October 2012) at IIMR and late planting (5 December 2012) at Mahabaleshwar. The experimental material experienced a temperature of 10–15°C at Mahabaleshwar and 13–15°C during anthesis at Hyderabad.

Genetic material included breeding lines and germplasm. The breeding material consisted of 16 restorer lines (R-lines), 11 maintainer lines (B-lines), 44 varieties and 10 hybrids. The germplasm consisting of 113 lines that included 73 lines of Indian origin and with *rabi* adaptation and 40 photoperiod-sensitive lines of exotic origin (three lines from Zimbabwe, six from Yemen, two from USA, two from Uganda, five from Sudan, two from South Africa, two from Malawi, two from Cameroon, eleven from Ethiopia, one each from Niger, Nigeria, Kenya, Indonesia and China) were acquired from the Indian Institute of Millets Research (IIMR), Hyderabad gene bank. All the breeding lines and germplasm were specific for *rabi* adaptation in order to maximize the chances of identifying sources for cold tolerance that can be directly used in breeding programmes. The materials were multiplied in 2011 post-rainy season at IIMR.

The experiments at both locations were planted in RCBD design with two replications. In experiment I, seedling growth parameters at 21 days after sowing and in experiment II, agronomic traits and yield components were recorded at maturity (Table 1). To determine the differences among genotypes for quantitative traits, variance analysis was performed. Pearson's correlation coefficients (r) between all the recorded parameters were calculated. Principal component analysis (PCA) was performed to evaluate the contribution of each qualitative and quantitative character to the total variations of genotypes. The genotypes were grouped based on their utilization in the breeding programme. The diversity/distance between the breeding groups was assessed by measuring the inter-cluster distances using Mahalanobis distance (D^2). Discriminant analysis was used to assess if the genotypes conformed to the groups they were classified into. Data analysis was carried out using Genstat 12th edn.

Analysis of variance performed on the quantitative data showed significant ($P \leq 0.05$) variation among the 194 sorghum genotypes for all traits. The genotypes were divided into various breeding groups such as varieties (44 genotypes), B-lines (11), R-lines (16), hybrids (10) and germplasm lines (113). The coefficient of variation (CV), also known as relative standard deviation (RSD), is a standardized measure of dispersion. It shows the extent of variability in relation to the mean of the population. It is used for comparison between datasets with different units or widely different means. Among the traits, the seedling dry fodder yield and grain yield showed highest CV. The B-lines and hybrids were more variable for percentage of seed set while the germplasm lines were more variable for 100-grain weight. Among the groups, varieties showed greater CV for the trait seedling vigour. B-lines were most variable for seedling height, plant height, leaf length, panicle width and panicle harvest index. R-lines were most variable for the number of primaries, hybrids for grain yield and percentage of seed set and germplasm lines for seedling leaf number, seedling dry fodder yield,

Table 1. Full name, abbreviation and descriptions of the traits studied

Trait name	Abbreviation	Description
Number of leaves	NL	Number of leaves averaged over five plants was counted.
Seedling vigour	SV	Seedling vigour was visually rated using a 1–5 scale, where 1 is excellent and 5 is poor.
Seedling length	SL	Seedling length was determined as an average height from five seedlings.
Seedling dry weight	SDW	Seedling dry weight was measured from the seedlings sampled from each plot after drying in an oven for five days and extrapolated for hectare.
Days to flowering	DF	This was calculated as the days required for 50% of the plants in a plot to have 50% anthesis.
Plant height	PHT	Plant height was recorded as the length from the base of the plant to the tip of the panicle.
Leaf length	LL	Leaf length was measured as the length from the base of the ligule to the tip of the leaf from five randomly selected plants and the mean calculated.
Leaf width	LW	Leaf width was measured by taking the width of the widest section of the leaf from five randomly selected plants and the mean calculated.
Panicle length	PL	Panicle length (cm) was measured from the base to the tip of the panicle from five randomly selected plants per plot at maturity and averaged.
Panicle width	PW	Panicle width is measured at the widest diameter of the panicle on five randomly selected plants per plot at maturity and averaged.
Number of primaries	NoP	Number of primaries was recorded for five random plants per plot and averaged.
Grain yield	GY	This was calculated as the total grain weight per plot (kg) after threshing and then converted into kilograms per hectare.
Panicle harvest index	PHI	It is the ratio of total grain weight to the total panicle weight.
100-grain weight	100-GWT	Weight of 100 grains (g).
Percentage of seed set	%SS	Three primaries were picked randomly from the bottom, middle and top one-third of the panicle. The number of sessile spikelets with and without seed was counted. Percentage of seed set was estimated as the number of sessile spikelets with seeds/total number of sessile spikelets × 100. Average of five plants was recorded.

days to 50% flowering, leaf width, panicle length and 100-grain weight.

Varieties performed best for seedling height (16.4 cm), plant height (233 cm) and leaf length (66 cm). B-lines performed best for seedling vigour (1.8) and panicle length (23 cm). R-lines performed best for leaf length (66 cm), panicle width (5.5 cm), grain yield (3540 kg/ha) and panicle harvest index (72.8). Hybrids performed best for most of the seedling traits such as seedling vigour (1.8), seedling leaf number (5.5) and seedling dry fodder yield (29.6 kg/ha), indicating their early vigour. Apart from this, they were early flowering (74 days). Germplasm lines were early flowering (74 days) and had more seedling leaf number (5.5), greater leaf width (6.6 cm), more number of primaries (54.7), greater seed weight (3.6 g per 100 grains) and better percentage of seed set (80.5) compared to the other groups (Table 2).

The seedling dry fodder yield, representing cold tolerance at seedling stage, was significantly associated with all other seedling traits (greater seedling vigour and height and more number of leaves), early flowering, low panicle harvest index, lower number of nodes and primaries. Percentage of seed set and grain yield were significantly and positively associated with each other (0.36) as well as with seedling height, plant height, grain size, number of nodes, leaf length and width, panicle width and number of primaries, and negatively associated with panicle length. While percentage of seed set was significantly and negatively associated with panicle harvest index (–0.09*), grain yield was positively and significantly associated with it (0.22**). Panicle harvest index was significantly associated with less number of leaves at seedling stage, low seedling dry fodder yield, late flowering, greater plant height and grain yield, smaller grain size, narrow width of leaves, greater panicle length and width, less number of primaries and poor seed set (Table 3).

PCA showed that out of the ten principal components (PCs), the first five explained majority of the total variation. These five PCs with eigenvalue >1 contributed 66.5% of the total variability amongst the sorghum genotypes assessed for various morpho-physiological traits (Table 4). PC I contributed maximum towards the variability (29.01%) followed by PC II (13.38%), PC III (9.8%), PC IV (7.46%) and PC V (6.83%). PC I was explained by variations among accessions mainly for traits such as grain yield, number of nodes, leaf length, leaf width, plant height and panicle width, which had positive factor loading on PC I. Similarly, PC II was related to diversity among sorghum genotypes due to seedling dry fodder yield, seedling leaf number, seedling plant height and seedling vigour, and which had negative loading. PC III was explained mainly by the variation among genotypes that resulted from 100-grain weight, days to 50% flowering, panicle harvest index, panicle length and percentage of seed set. In this PC, panicle length showed a negative contribution, PC IV was explained negatively by variations resulting from days to 50% flowering and leaf width, and positively by plant height and seedling height. PC V was explained positively by variations resulting from panicle harvest index and panicle length, and negatively by the number of primaries and seedling height (Table 4). Discriminant

Table 2. Performance of genotypes belonging to diverse breeding groups for agronomic and yield traits under screening for cold stress at seedling stage and anthesis

	Traits recorded at seedling stage					Traits recorded at flowering, maturity and post-harvest stages									
Breeding group	Seedling vigour	Seedling leaf number	Seedling height (cm)	Seedling dry fodder/ ha (kg)	Days to 50% flowering	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Panicle length (cm)	Panicle width (cm)	Number of primaries	Grain yield/ha (kg)	Panicle harvest index	100-grain weight (g)	Seed set (%)
Varieties (44)															
Mean	2.0	5.3	16.4	21.7	85	233	66.0	6.2	19.0	5.4	52.3	3379	72.2	3.3	80
Minimum	1.0	4.5	11.5	4.2	68	148	59.5	5.2	11.5	3.7	29.0	1561	52.5	2.0	49
Maximum	3.6	6.5	22.5	63.3	102	298	76.0	7.8	25.5	7.0	74.0	5862	79.0	3.9	92
SD	0.5	0.5	2.7	13.4	7	32	3.9	0.7	3.1	0.7	9.1	1016	5.1	0.4	7.9
CV	26.9	8.7	16.6	61.7	8	14	6.0	10.8	16.3	12.6	17.4	30	7.1	11.6	9.9
B-lines (11)															
Mean	1.8	5.4	14.5	25.0	86	178	61.8	5.7	23.0	5.0	47.4	2485	63.1	2.9	68
Minimum	1.6	5.0	11.0	7.7	72	125	42.5	3.8	16.5	2.7	32.0	647	41.0	1.3	6
Maximum	2.5	6.0	20.0	50.9	101	260	71.5	6.6	30.5	6.3	61.5	4302	78.5	4.0	85
SD	0.3	0.3	3.1	13.2	8	39	7.5	0.7	4.5	1.0	8.4	1014	12.3	0.9	22.1
CV	16.0	6.4	21.1	52.6	9	22	12.1	13.0	19.4	20.9	17.7	41	19.5	29.7	32.3
R-lines (16)															
Mean	2.0	5.0	15.4	15.7	80	218	66.0	6.4	18.9	5.5	51.9	3540	72.8	3.3	79
Minimum	1.6	4.5	11.5	4.9	71	135	57.5	5.0	15.9	4.0	28.0	1670	61.5	2.7	65
Maximum	2.6	5.5	21.0	31.8	94	268	78.0	8.0	25.2	6.5	83.0	6630	81.0	4.3	90
SD	0.5	0.3	2.4	8.6	8	30	6.0	0.9	3.1	0.8	13.0	1166	4.7	0.5	8.3
CV	23.2	5.8	15.3	54.8	10	14	9.2	14.3	16.5	14.2	25.1	33	6.5	14.7	10.5
Hybrids (10)															
Mean	1.8	5.5	15.2	29.6	74	198	62.6	6.1	*	*	*	1484	*	3.5	42
Minimum	1.6	4.5	13.0	13.2	70	145	53.5	5.3	*	*	*	0	*	2.5	0
Maximum	2.0	6.0	18.0	47.0	81	245	66.2	6.7	*	*	*	3560	*	4.6	90.0
SD	0.2	0.5	1.4	12.8	3	28	4.0	0.4	*	*	*	1408	*	0.5	37.1
CV	11.4	9.6	9.2	43.3	4	14	6.4	6.8	*	*	*	95	*	15.6	88.4
Germplasm lines (113)															
Mean	2.0	5.5	16.1	24.7	74	197	64.5	6.6	16.7	5.2	54.7	2848	70	3.6	81
Minimum	1.0	4.5	9.0	2.0	50	145	43.0	3.8	8.4	2.5	30.0	417	40	1.2	35
Maximum	3.6	7.5	24.0	83.3	146	255	78.7	9.8	31.1	7.5	92.0	5991	90	8.3	95
SD	0.5	0.6	2.5	16.2	10	26	7.5	1.1	4.6	0.9	13.0	1153	10	1.1	8.8
CV	24.1	11.0	15.6	65.5	13	13	11.7	16.1	27.4	17.8	23.8	40	12.5	31.5	11.0

Table 3. Correlation among the agronomic and yield traits recorded under screening for cold stress at seedling stage and anthesis

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Seedling vigour (1)	1.00														
Seedling leaf number (2)	–0.25**	1.00													
Seedling plant height (3)	–0.21**	0.22**	1.00												
Seedling dry fodder/ha (kg) (4)	–0.57**	0.46**	0.35**	1.00											
Days to 50% flowering (5)	0.03	–0.28**	0.12**	–0.22**	1.00										
Plant height at maturity (6)	0.03	–0.15**	0.33**	–0.06	0.33**	1.00									
Grain yield (7)	0.03	–0.06	0.26**	–0.01	0.27**	0.56**	1.00								
Panicle harvest index (8)	–0.06	–0.26**	–0.04	–0.14**	0.49**	0.38**	0.22**	1.00							
100-grain weight (g) (9)	0.12**	–0.07*	0.10**	–0.04	–0.03	0.13**	0.22**	–0.14**	1.00						
Number of nodes (10)	0.04	–0.08*	0.38**	–0.08*	0.34**	0.58**	0.56**	0.04	0.24**	1					
Leaf length (11)	–0.08*	–0.02	0.22**	0.02	0.20**	0.47**	0.58**	0.06	0.10**	0.54**	1.00				
Leaf width (12)	0.04	–0.01	0.12**	–0.05	0.08*	0.23**	0.53**	–0.24**	0.21**	0.49**	0.77**	1.00			
Panicle length (13)	–0.06	–0.01	–0.26**	0.02	0.07*	0.02	–0.15**	0.30**	–0.25**	–0.32**	–0.04	–0.24**	1.00		
Panicle width (14)	–0.01	0.02	0.20**	–0.05	0.19**	0.40**	0.65**	0.13**	0.11**	0.47**	0.53**	0.46**	–0.04	1.00	
Number of primaries (15)	0.12**	–0.01	0.24**	–0.14**	0.15**	0.22**	0.40**	–0.12**	0.12**	0.46**	0.41**	0.39**	–0.25**	0.52**	1.00
Percentage of seed set (16)	0.03	–0.12**	0.15**	–0.05	–0.01	0.30**	0.36**	–0.09*	0.22**	0.32**	0.25**	0.24**	–0.24**	0.27**	0.22**

*Significant at 5%; **Significant at 1%.

Table 4. Eigenvalue total variance, cumulative variance and eigenvector for 16 quantitative characters in sorghum

Character	PC 1	PC 2	PC 3	PC 4	PC 5
100-grain weight	0.15	0.06	**0.38**	0.09	–0.08
Days to 50% flowering	0.15	0.18	**–0.42**	**0.38**	–0.18
Seedling dry fodder/ha (kg)	–0.04	**–0.59**	0.02	0.10	0.12
Grain yield/ha (kg)	**0.38**	–0.02	–0.04	0.02	0.22
Panicle harvest index	0.18	0.09	**0.39**	0.18	**0.46**
Leaf length (cm)	**0.35**	–0.09	–0.21	–0.28	0.12
Leaf width (cm)	**0.33**	–0.03	0.04	**–0.43**	0.09
Seedling leaf number	–0.05	**–0.47**	0.06	–0.26	–0.12
Number of nodes	**0.37**	–0.01	–0.05	0.13	–0.25
Plant height (cm)	**0.30**	0.02	–0.24	**0.36**	0.08
Panicle length (cm)	–0.15	0.03	**–0.53**	–0.06	**0.41**
Panicle width (cm)	**0.34**	–0.04	–0.15	–0.22	0.10
Number of primaries	0.28	0.02	0.00	–0.29	**–0.37**
Seedling height (cm)	0.19	**–0.36**	0.04	**0.36**	**–0.36**
Seed set (%)	0.23	0.04	**0.31**	0.19	0.29
Seedling vigour	0.03	**0.49**	0.12	–0.16	–0.23
Eigenvalues	4.64	2.14	1.57	1.19	1.09
Percentage of total variance	29.01	13.38	9.80	7.46	6.83
Percentage of cumulative variance	29.01	42.39	52.19	59.65	66.48

Table 5. Summary of the discriminant analysis of the four groups

Group	No.	True group			
		Varieties	B-lines	R-lines	Germplasm lines
Varieties	44	34	3	4	3
B-lines	11	2	8	1	0
R-lines	16	3	1	12	0
Germplasm lines	113	3	4	11	95
Percentage correct		77	73	75	84

Table 6. Intergroup distances – Mahalanobis (D^2)

	Varieties	B-lines	R-lines	Germplasm lines
Varieties	0.00	5.96	1.57	6.97
B-lines	5.96	0.00	5.98	11.89
R-lines	1.57	5.98	0.00	6.09
Germplasm lines	6.97	11.89	6.09	0.00

analysis using the type of breeding group as a grouping variable revealed that 149 out of 184 genotypes (81%) were correctly classified to their breeding groups (Table 5). The percentage of genotypes correctly classified was relatively high for germplasm lines followed by varieties, R-lines and B-lines. The relationships among the groups were assessed by measuring the inter-group distances using Mahalanobis distance (D^2). The lowest inter-group distance (1.57 units) was between R-lines and varieties. The highest inter-group distance (11.89 units) was between B-lines and germplasm lines (Table 6).

Being a crop of the tropics, sorghum is sensitive to cold temperature compared to other crops such as maize. The crop experiences poor stand establishment and growth due to cold temperature stress at the seedling stage and poor seed set when exposed to cooler night temperature at anthesis, especially in hybrids. Five groups involving 194 genotypes were included in the present study. The crop expressed differential performance based on the breeding group involved. Seedling growth was greatly affected by exposure to cold stress at the seedling stage. This might be due to the effect of cold temperature on key cellular functions and photosynthetic activity[6]. The genotypes were variable for all the traits. Similar genotypic differences were earlier observed in sorghum on exposure to cold stress[1]. All the groups exhibited the highest CV for the economically important parameters such as seedling dry fodder yield and grain yield. Apart from these traits, high CV was exhibited by B-lines and hybrids for percentage of seed set, and by the germplasm lines for 100-grain weight. This signifies the existence of a high degree of variability with regard to these traits in the individual groups. The results also indicate that there is scope for improvement of seedling dry fodder yield and grain yield, which are important traits indicative of tolerance to cold stress at the two stages, in all the groups. It is well known that the hybrids involving winter sorghum genotypes show poor seed set and the present findings indicate that there is scope for improvement in the hybrids as well as female parental lines of the hybrids (B-lines). Earlier reports also indicated similar results[7]. Among other parameters, greater variability was observed in varieties for seedling vigour, B-lines for panicle harvest index, R-lines for the number of primaries, and hybrids for grain yield and percentage of seed set, indicating scope for further improvement within these groups for these important traits. The need for improvement of these traits in winter sorghum was also considered in another study[8]. Mean performance among the groups indicated that the R-lines had good grain yield, while the hybrids were more tolerant to cold stress at the seedling stage. The genotypes BRJ 356B and 104B among the B-lines, IS 34723, EP 109 and EP 13 among the germplasm lines, CRS 19 and CRS 1 among the R-lines, CSV 18R and Phule Vasudha among the varieties were the best performing for most traits and these should be extensively used in breeding programmes. Only one hybrid, 401A × 972 was on par with CSH 15R, the hybrid released for winter season cultivation. As was experienced earlier[8], the hybrids developed based on existing parental lines of winter sorghum are not promising. Hence targeted breeding efforts are required for developing new parental lines, finally leading to the development of cold-tolerant hybrids. Also the significant association between seedling dry fodder yield and low panicle harvest index needs to be broken through simultaneous selection for both traits. This also indicates poor association of cold tolerance at the two growth stages, which was also observed by non-significant correlation of grain yield with seedling dry fodder yield. In addition, except seedling height, all other seedling traits were not associated with most traits recorded at maturity. Similar results were observed by Maulana and Tesso[1]. However at maturity, the negative association of panicle harvest index with percentage of seed set and other yield parameters needs to be broken. Contrasting genotypes for both traits have to be crossed and selection needs to be done for progenies with both good percentage of seed set under selfing and panicle harvest index.

Thus, the first two PCs differentiated between traits recorded at seedling and maturity stages. These results are similar to those obtained earlier on different agro-morphological traits in sorghum[9,10]. Moreover, PCA also showed that variation in sorghum genotypes cannot be explained on the basis of a few characters. This, in turn, implies that several traits are involved in explaining the gross variance among genotypes. This further confirms previous results that also described the importance of these traits in contributing towards the overall diversity in sorghum[11,12]. Discriminant analysis revealed that 81% of the genotypes were correctly classified to their breeding groups. The percentage of genotypes correctly classified was relatively high for germplasm lines followed by varieties, R-lines and B-lines. These results are in agreement with the hypothesis made earlier[13,14] that higher the diversity of the group, the higher is the probability of misclassification and vice versa. According to the Mahalanobis distance (D^2), the lowest inter-group distance (1.57 units) was found between R-lines and varieties, while the highest inter-group distance (11.89 units) was between B-lines and germplasm lines. Crossing accessions belonging to different groups of wide Mahalanobis distance (D^2) could maximize opportunities for transgressive segregation as there is a higher probability that unrelated genotypes would contribute unique desirable alleles at different loci[15,16]. This result suggests that maximum variability can be obtained by crossing B-lines with germplasm lines; while B-lines can be moderately diversified by crossing with R-lines/varieties. Similarly, the same amount of diversity can be obtained by crossing R-lines/varieties with B-lines/germplasm lines.

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