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RESEARCH ARTICLE :

Biplot analysis of combining ability in elite *Rabi* sorghum genotypes under irrigated and drought situations

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SUMMARY : Sorghum is a fifth most important cereal grown extensively in the arid and semi arid tropics. Among sorghum growing countries, India ranks first in acreage and second to the USA in total production. In India sorghum is cultivated as *Kharif* and *Rabi* season crop. *Rabi* sorghum is predominantly consumed for food purposes but its productivity is much lower (784kg/ha) as compared to *Kharif* sorghum (1023kg/ha). The main reason for lower productivity of *Rabi* sorghum is post-flowering drought stress as the crop is predominantly cultivated in receding soil moisture. Understanding the genetics of drought tolerance is a prerequisite of their deployment in breeding programme. With this goal complexity of eight traits of eight sorghum lines were studied. A set of 8 ´ 8 diallel cross was evaluated in well watered and water stressed conditions and analyzed using GGE biplot. The biplot depiction of the interaction among the parents helped easy and fast interpretation of the combining abilities. Under well watered condition, the best general combiner for Plant yield, Plant height, SPAD, leaf number, panicle weight, seed weight, days to flowering, dry weight were CSV22, CSV22, P. Anuradha, IS40772, CSV22, IS40752, IS40772 and IS40752 respectively. Under water stressed condition IS 23514 found to be best combiner for plant yield while CSV22,M35-1, IS40772, P. Chitra, IS40752, IS4578, IS23514 were best combiners under this situation for plant height, SPAD, leaf number, panicle weight, seed weight, days to flowering and dry weight respectively. The GGE biplot aided to identify genotypes with highest specific combining abilities. For example, IS23514 found to be the best specific combiner in well watered condition while IS40752 found to be the best specific combiner in water stressed condition for the trait plant height. The biplot also helped in identifying promising specific combiners, like P. Anuradha x IS40752 for the trait Days to flowering. Identified parents and crosses with better specific combining abilities can be successfully be deployed in drought resistance breeding programme.

KEY WORDS :
Genotypes, Sorghum, Combining ability, Drought situations

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BACKGROUND AND OBJECTIVES

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal worldwide after maize, wheat, rice and barley (Kholova *et al.*, 2013). Due to its remarkable ability to produce a crop under adverse conditions, it can be cultivated extensively in marginal rainfall areas of the tropics and semi-arid tropics for its better adaptation to various stresses, including drought, heat, salinity and flooding (Harris *et al.*, 2006; Ejeta and Knoll 2007) throughout the world as a source of food, feed, fodder and biofuel (Duncan 1996). Under changing climatic conditions with less availability of water and elevated level of $C0_2$ being a C_4 drought species it assumes more importance. Sorghum is cultivated in nearly 42.3 mha with an annual production of 61.5million tons in the world (FAO 2014). Among sorghum growing countries, India ranks first in acreage and second to USA in production (Rakshit *et al.*, 2014a). In India sorghum grown in an area of 6.32 million hectare with total production of about 6.01 million tons (FAO 2014). This is much below as compared to USA (4.51kg/h), Mexico (3.92kg/h), Ethiopia (1.85kg/h) and other. The main reason for low productivity of sorghum in India is susceptibility of sorghum to different biotic and abiotic stresses. In India sorghum is cultivated as *Kharif* and *Rabi* season crop. *Rabi* sorghum is predominantly consumed as food grain (Rakshit *et al.*, 2012, Ganapathy *et al.*, 2012) but its productivity is much lower (784kg/ha) as compared to *Kharif* sorghum (1023kg/ha) (Patil *et al.*, 2013) The main reason for lower productivity of *Rabi* sorghum is post-flowering drought stress as the crop is predominantly cultivated in receding soil moisture. Water deficit is one of the major abiotic stresses limiting crop productivity in the semi arid tropics and this is the serious agronomic problem, which limits agricultural production by preventing the crop plants from expressing their full genetic potential. Drought tolerance is a stage specific trait and changes during life cycle. The effect of drought stress depend not only on the duration and intensity of deficiency, but also on developmental phase in which it began (Szira *et al.*, 2008). The influence of drought may relatively be addressed through genetic improvement for drought response (Mutuva *et al.*, 2011). Thus, identification of drought tolerant lines among *Rabi* adapted genotypes is prerequisite to deploy them in breeding programme.

Any breeding technique aiming to develop improved varieties and nutrition security needs to be incorporated to target those major constraints. The success of sorghum breeding programme is related to the appropriate choice of divergent parents which, when crossed, must provide wide genetic variability to be used for selection. Diallel analysis provides a systematic approach for detection of appropriate parents and crosses as it allows estimation of different genetic parameters including the expression of heterosis in early generations. Higher yield values can be obtained by hybridizing superior cultivars. Understanding the genetics of drought tolerance is a prerequisite of their deployment in breeding programme. With this goal complexity of eight traits of eight sorghum lines were studied. A set of 8 ´ 8 diallel cross was evaluated in well watered and water stressed conditions and analyzed using GGE biplot. A biplotis a scatter plot that graphically represents the relationship among the factors and underlying interactions between them and can be visualised simultaneously (Rakshit *et al.* 2012). Two types of biplots viz., the AMMI biplot (Crossa 1990; Gauch 1992) and the GGE biplot (Yan *et al.*, 2000; Yan and Kang 2003) are the most commonly used biplots to understand GEI. Genotype (G) main effect plus genotype and environment (GE) interaction (GGE) biplot analysis (Yan W & Keny 2003) is a robust method to visualize and interpret data graphically. With the help of GGE biplotanalaysis, Genotype environment interaction has been demonstrated in many of the crops including sorghum. (Rakshit *et al.*, 2012, Rao, 2011).The biplot depiction of the interaction among the parents helped easy and fast interpretation of the combining abilities. Recently, GGE biplot has been applied in genetic analysis of diallel crosses to estimate the combining abilities of parents. (Akinwale *et al.*, 2014). Yan and Holland (2010) demonstrated the use of heritability-adjusted-GGE biplot for evaluation of test locations and genotypes.

RESOURCES AND METHODS

Material used in the present study were eight parents and their 28F1 crosses. The experiment was conducted during *Rabi* season at Indian institute of Millets Research (IIMR), Hyderabad, India. Based on the performance of the genotypes in multi location environments and their genetic diversity, 8 sorghum genotypes exhibiting high levels of resistance (IS 40772, IS 40752, IS 4578, IS 23514, M35-1, P. Chitra, P. Anuradha, CSV22) were selected for diallel programme. The crop was sown on Oct 23, 2013. Two sets of diallel crosses each involving 36 genotypes (8 parents+28F_1s) were sown in one row plot of 6m length with 60cm row to row spacing and 15cm plant-to-plant spacing in randomized complete block design. This wider row spacing was used to facilitate supplemental irrigation when needed. 4-5 seeds were sown per hill and thinned to 1 plant per hill 15 days after emergence to maintain optimum plants per plot. Irrigation was applied immediately after sowing and at 15, 30 and 45 days after sowing (DAS) in both experimental plots for proper germination and establishment. Water was withdrawn immediately after booting stage in one of the experimental plot and another set was irrigated continuously when required. Data was recorded on five randomly selected plants in each row. SPAD data was recorded after 50% flowering from first three leaves including flag leaf. SPAD values was measured at three different points on each leaf. Average of three values was recorded as SPAD data for one plant. Days to flowering was recorded after 50% flowering. Plant height was evaluated visually on a 50-250m scale. Number of leaves was recorded by counting all the leaves. After grain maturity, weight of the panicles was taken from the five selected plants. Single plant yield was calculated by taking seed weight of single panicle after threshing. Seed weight was recorded by taking the weight of 100 seeds. Single plant yield and Dry weight were recorded for each plant, whereas data on phenological traits such as days to 50% flowering and seed weight were recorded on plot basis.

Data analysis :

Among various statistical methods, biplot analysis is an important multivariant tool that graphically displays results and therefore, facilitates easy interpretation of the data. In biplot analysis of diallel data, scaling to use was 'Scale=0' which enables to estimate the discriminating ability of the parents. In the average tester co-ordination view of the GGE biplot, the longer the projections on the one headed arrow, the higher the SCA effects. 'Mean vs. stability' option of GGE biplot software was used to evaluate genotype using genotype focused singular value partitioning (SVP=1) (Rakshit *et al.*, 2014b).

OBSERVATIONS AND ANALYSIS

Combined analysis of variance for grain yield of the 36 (eight parents, 28F$_1$s) sorghum cultivars tested in two different environmental conditions explained highest proportion of variation for grain yield.

Identification of stable genotypes with highest mean performance :

In GGE biplot the complex GEIs are partitioned in different principal components(PCs) and the data are presented graphically against various PCs (Yan and Tinker 2006). Fig. 1 depicts the GGE biplot summarizing mean performance and stability of genotypes using average environment coordination (AEC) method. Projection of a genotype over AEC abscissa (line with single arrow head) indicates its average yield, while dispersion of the genotype along the AEC ordinate (double arrowed line is indicative of its stability. The greater the absolute length of the projection of a cultivar, the less stable it is (Yan *et al.*, 2000).

Trait wise stability and mean performance of the genotypes are discussed below :

Under well watered condition, the best general combiner for plant yield was CSV22 and gcaeffects ranged from -5.71(M35-1) to 6.16(CSV22). Under water stressed condition, the best general combiner was IS23514 and gca effects ranged from -3.04(IS40772) to 4.43 (IS23514) in water stressed conditions. The genotypes IS40772 (-1.24,-3.04), IS40752 (-0.47, -2.09), M35-1(-5.71,-2.39), P. Anuradha (-1, -0.62) exhibited negative and significant gca effects in both the environmental conditions. The GGE biplot aided to identify genotypes with highest specific combining abilities. Under well watered condition and in water stressed condition, IS40772 and P.Anuradha found to be the best specific combiner for the trait Plant yield respectively.

For the trait, plant height CSV22 found to be the best general combiner in both the environmental conditions. gca effects ranged from from -9.62* (IS 23514) to 17.7*(CSV22) in well watered condition. and in water stressed condition gca effects varied from -11.43* (IS 23514) to 8.5 *(CSV22). From the GGE biplot analysis, IS23514 found to be the best specific combiner under well watered condition and IS40752 found to be the best combiner under water stressed condition.

For SPAD, gca effects ranged from -2.93*(P.Chitra) to 2.84*(P.Anuradha) in well watered conditions and P.Anuradha found to be the best general combiner. Under water stressed conditions, M35-1 found to be the best general combiner and gca effects varied from -4.53* (IS40752) to 2.48*(M 35-1). From GGE biplot analysis CSV22 found to be the best specific combiner under well watered condition and in water stressed condition IS40752 found to be the best specific combiner.

The gca effects for Leaf number varied from

Table 1 : Mean for Morphological Traits

Genotype	PY		PH		SPAD		LfNo		Panwt		SW		DTF		DryWt	
	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
G1	40.05	25.05	189.65	158.35	55.35	35.60	12.40	10.60	72.10	41.90	4.05	3.70	80.50	72.50	265.92	195.00
G2	41.20	25.87	199.45	182.10	55.20	35.50	11.65	10.00	69.00	39.90	5.60	4.45	78.50	76.00	280.00	112.50
G3	38.85	25.49	173.50	151.15	55.20	43.70	11.75	10.90	70.50	41.90	5.25	4.35	81.50	74.00	268.55	215.95
G4	37.05	23.20	144.60	123.75	49.40	45.80	9.60	8.75	62.50	33.50	3.90	3.00	74.50	68.50	204.42	194.34
G5	39.35	24.35	169.15	152.80	54.40	51.20	9.60	8.50	62.10	35.10	4.90	4.00	74.50	70.50	92.50	71.71
G6	41.20	26.35	195.50	169.05	50.70	39.50	11.35	10.95	70.90	39.30	4.70	4.30	80.50	75.00	180.00	157.50
G7	39.30	24.75	175.50	150.85	63.15	48.85	11.60	8.95	63.70	38.20	4.10	3.95	73.00	70.00	179.49	127.50
G8	43.85	26.97	215.00	176.00	58.50	41.00	11.60	10.60	80.70	48.60	5.45	3.90	82.50	76.50	183.80	170.23
G1*G2	34.55	18.00	188.50	171.50	53.00	37.80	14.65	11.15	48.95	42.90	5.65	4.50	78.50	74.50	222.50	112.50
G1*G3	36.55	18.92	189.30	177.70	56.00	51.15	11.66	10.41	49.80	38.50	6.15	4.50	82.50	76.00	265.00	104.96
G1*G4	38.70	37.05	206.80	190.20	61.00	51.60	11.95	9.85	54.80	63.50	5.60	4.75	74.50	69.00	392.50	347.26
G1*G5	35.20	21.20	189.95	181.75	63.55	46.80	12.70	9.00	50.40	31.90	5.20	4.35	74.50	71.00	200.00	170.00
G1*G6	48.25	32.82	194.60	180.75	53.65	52.45	12.80	10.35	62.45	65.30	5.00	4.75	76.50	70.50	248.01	174.61
G1*G7	33.05	17.20	188.50	149.25	60.20	42.50	12.60	11.20	45.60	36.10	5.00	3.80	74.00	67.00	175.51	140.00
G1*G8	52.25	21.60	207.25	187.25	56.40	43.80	13.40	10.95	68.00	54.80	5.40	4.75	77.00	71.00	290.00	179.88
G2*G3	38.50	22.38	183.70	167.80	52.60	47.30	11.50	9.70	50.70	37.30	6.80	4.00	77.50	75.00	317.44	95.00
G2*G4	39.90	34.95	201.90	188.60	57.30	45.95	10.00	8.60	54.25	56.90	4.90	4.95	74.00	70.00	247.50	192.50
G2*G5	35.50	23.95	200.50	194.95	56.00	41.30	10.70	9.30	51.05	37.30	5.75	4.95	71.50	67.00	225.00	140.00
G2*G6	46.19	31.20	189.00	138.05	49.95	48.00	9.90	9.20	58.60	54.50	6.00	5.25	78.50	73.00	267.50	227.05
G2*G7	38.00	21.15	192.00	175.95	63.35	36.70	10.00	9.15	48.85	38.70	5.40	4.60	70.00	67.00	244.50	165.61
G2*G8	51.30	23.02	207.50	182.00	54.85	40.30	12.30	9.90	66.95	50.90	5.40	4.40	76.00	69.50	280.17	105.00
G3*G4	41.20	33.80	177.70	150.70	54.45	48.30	10.90	9.18	53.70	55.80	5.55	4.25	74.50	70.50	200.00	155.00
G3*G5	32.20	24.90	197.50	180.30	55.75	48.25	11.20	10.10	50.15	31.40	5.25	4.75	72.00	68.50	157.50	127.50
G3*G6	48.15	33.34	185.15	165.35	53.20	49.20	10.30	9.00	61.75	60.30	5.15	4.25	76.50	72.00	300.00	162.50
G3*G7	40.20	36.58	179.00	159.10	56.00	48.25	11.35	9.90	50.35	60.10	5.60	4.80	74.00	74.00	257.50	177.50
G3*G8	51.15	28.70	213.50	170.90	51.40	47.45	11.00	10.40	66.80	52.80	5.40	5.05	78.00	73.50	250.00	175.00
G4*G5	35.10	35.58	154.50	141.35	52.80	50.45	10.90	9.10	49.10	17.60	4.00	2.80	74.50	70.50	197.50	155.00
G4*G6	47.30	32.55	194.00	160.55	51.65	48.10	8.80	8.70	61.50	56.80	4.35	3.50	74.50	69.50	230.00	176.27
G4*G7	37.30	33.25	190.50	140.80	54.50	44.40	11.70	9.90	69.10	47.80	5.00	4.10	72.50	70.00	282.50	121.30
G4*G8	53.10	38.05	212.00	168.00	52.85	49.00	11.75	10.50	90.80	62.40	3.90	3.25	74.00	69.50	250.29	220.91
G5*G6	32.29	23.15	195.00	170.95	54.45	54.05	10.85	9.15	67.10	36.10	5.75	4.50	72.00	70.50	205.00	156.57
G5*G7	32.30	22.98	181.50	162.25	54.75	49.55	11.10	10.05	67.00	29.60	5.05	3.95	74.50	72.00	195.12	175.00
G5*G8	32.70	22.95	208.50	169.60	66.65	45.70	10.55	8.00	68.10	31.90	4.75	4.00	70.00	66.00	232.50	157.50
G6*G7	48.00	34.15	179.50	161.15	53.80	50.00	10.85	9.20	71.10	55.80	5.35	5.00	74.50	70.50	205.00	142.50
G6*G8	50.85	37.45	212.50	178.30	54.65	51.10	13.85	11.50	82.30	65.10	5.55	4.10	76.00	73.50	280.00	230.00
G7*G8	53.65	26.35	208.55	178.95	61.50	44.10	13.40	10.90	107.40	53.80	6.55	5.20	79.50	73.50	145.00	32.50
LSD (0.05)	13.50	12.31	32.41	33.32	8.25	9.97	2.56	1.82	26.54	24.35	1.40	1.19	6.63	5.60	112.62	108.65

Table 2 : Estimates of general combining ability

Genotypes	PY		PH		SPAD		LfNo		Panwt		SW		DTF		DryWt	
	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
G1	-1.24*	-3.04*	2.14*	5.31*	1.25*	-1.64*	1.15*	0.57*	-4.53*	0.57	-0.08	0.01	1.66*	0.21	22.08*	17.82*
G2	-0.47*	-2.09*	3.92*	8.1*	-0.46	-4.53*	-0.07	-0.14	-5.22*	-1.28*	0.43*	0.29*	0.11	0.61*	26.01*	-17.84*
G3	-0.54*	0.23*	-5*	-2.79*	-1.22*	1.36*	-0.16	0.21*	-4.53*	0.89	0.36*	0.16*	1.61*	1.56*	18*	-1.17
G4	-0.44*	4.43*	-9.62*	-11.43*	-1.87*	1.57*	-0.79*	-0.51*	-1.13*	1.67*	-0.58*	-0.51*	-1.44*	-1.59*	10.46*	31.59*
G5	-5.71*	-2.39*	-5.71*	0.47*	1.07*	2.48*	-0.59*	-0.67*	-4.24*	-12.51*	-0.13*	-0.14*	-2.39*	-1.54*	-50.69*	-21.6*
G6	3.24*	3*	1.79*	-0.88*	-2.93*	1.82*	-0.3*	0.06	3.71*	6.14*	-0.03	0.13*	0.76*	0.76*	-0.90	14.35*
G7	-1*	-0.62*	-5.23*	-7.29*	2.84*	-0.05*	0.11	-0.02	1.73*	-1.28*	-0.07	0.07	-1.69*	-0.79*	-24.04*	-23.16*
G8	6.16*	0.47*	17.7*	8.5*	1.33*	-1.02*	0.64*	0.5*	14.22*	5.78*	0.10	-0.01	1.36*	0.76*	-0.90	0.02
LSD (0.05)	0.28*	0.98*	4.13*	3.02*	1.38*	1.3*	0.45*	0.37*	1.05*	3.85*	0.22*	0.21*	0.97*	1.15*	8.22*	7.79*

0.79*(IS23514) to 1.15* (IS40772) and -0.67*(M35-1) to 0.57*(IS40772) in well watered condition and water stressed conditionsrespectively. IS40772 found to be the best general combiner in both the environmental conditions. CSV22 found to be the best specific combiner in both the environmental conditions by using GGE biplot analysis.

For Panicle weight, in well watered condition, CSV22 found to be the best general combiner and gca effects varied from -5.22*(IS40752*) to 14.22* (CSV22) while in water stressed conditions gca effects varied from -12.51*(M35-1) to 6.14* (P.Chitra) and P.Chitra found to be the best general combiner. P.Anuradha and IS23514 found to be the best specific combiners in well watered condition and water stressed condition respectively.

The gca effects for seed weight varied from -0.58*(IS23514) to 0.43*(IS40752) in well watered conditions and from -0.51*(IS23514) to 0.29* (IS40752) in water stressed conditions. IS40752 found to be the best general combiner in both the environmental conditions. From the GGE biplot analysis IS4578 found to be the best specific combiner in well watered condition while in water stressed condition IS23514 found to be the best specific combiner.

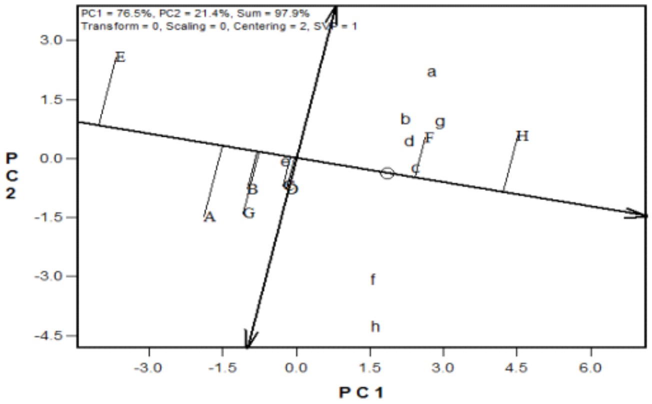
The gca effects of Days to flowering varied from -2.39*(M35-1) to 1.66*(IS40772) in well watered

Table 3 : Estimates of specific combining ability

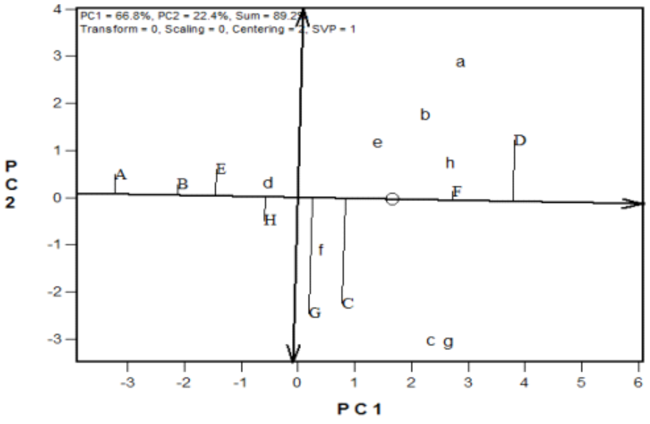
	SPAD		Plant height		LfNo		PanWt		Plant yield		SW		DTF		Drywt	
	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
1*2	-3.57*	-1.99*	-8.98*	-8.8*	2.12*	0.9*	-4.58*	-2.07	-4.97*	-4.34*	0.09	-0.10	0.96*	2.36*	-59.43*	-47.59*
1*3	0.20	5.46*	0.73	8.29*	-0.78*	-0.19	-4.42*	-8.64*	-2.9*	-5.75*	0.66*	0.03	3.46*	2.91*	-8.92	-71.8*
1*4	5.84*	5.7*	22.86*	29.43*	0.13	-0.04	-2.82*	15.58*	-0.85*	8.18*	1.04*	0.95*	-1.49*	-0.94	126.12*	137.74*
1*5	5.45*	-0.01	2.09	9.08*	0.68*	-0.72*	-4.1*	-1.84	0.92*	-0.85*	0.20	0.18	-0.54	1.01	-5.23	13.67*
1*6	-0.45	6.3*	-0.76	9.43*	0.50	-0.10	0.00	12.91*	5.03*	5.38*	-0.10	0.31*	-1.69*	-1.79*	-7.01	-17.67*
1*7	0.34	-1.78*	0.16	-15.66*	-0.12	0.83*	-14.87*	-8.87*	-5.94*	-6.62*	-0.06	-0.58*	-1.74*	-3.74*	-56.37*	-14.77*
1*8	-1.95*	0.50	-4.01	6.55*	0.16	0.06	-4.97*	2.77	6.1*	-3.31*	0.17	0.45*	-1.79*	-1.29*	34.98*	1.93
2*3	-1.50	4.51*	-6.65*	-4.41*	0.28	-0.19	-2.83*	-7.99*	-1.72*	-3.24*	0.81*	-0.75*	0.01	1.51*	39.6*	-46.11*
2*4	3.85*	2.95*	16.18*	25.04*	-0.59	-0.58*	-2.68*	10.83*	-0.42*	5.13*	-0.16	0.87*	-0.44	-0.34	-22.8*	18.63*
2*5	-0.39	-2.61*	10.86*	19.48*	-0.09	0.29	-2.77*	5.41*	0.45*	0.95	0.25	0.5*	-1.99*	-3.39*	15.85*	19.33*
2*6	-2.44*	4.75*	-8.14*	-36.06*	-1.18*	-0.54*	-3.17*	3.96	2.2*	2.81*	0.4*	0.54*	1.86*	0.31	8.56	70.43*
2*7	5.19*	-4.68*	1.88	8.24*	-1.49*	-0.51*	-10.94*	-4.42	-1.76*	-3.62*	-0.16	-0.05	-4.19*	-4.14*	8.70	46.5*
2*8	-1.8*	-0.11	-5.54*	-1.49	0.28	-0.28	-5.33*	0.72	4.38*	-2.84*	-0.33*	-0.17	-1.24	-3.19*	21.22*	-37.3*
3*4	1.76	-0.60	0.89	-1.97	0.40	-0.34	-3.92*	7.56*	0.95*	1.66*	0.56*	0.3*	-1.44*	-0.79	-62.3*	-35.54*
3*5	0.12	-1.56	16.78*	15.72*	0.50	0.74*	-4.36*	-2.66	-2.78*	-0.42	-0.18	0.43*	-2.99*	-2.84*	-43.64*	-9.84
3*6	1.57	0.05	-3.07	2.13	-0.69*	-1.09*	0.71	7.59*	4.23*	2.63*	-0.38*	-0.34*	-1.64*	-1.64*	49.07*	-10.79*
3*7	-1.39	0.97	-2.20	2.28	-0.05	-0.11	-10.13*	14.81*	0.51*	9.49*	0.11	0.27	-1.69*	1.91*	29.71*	41.72*
3*8	-4.48*	1.15	9.37*	-1.70	-0.93	-0.13	-6.17*	0.45	4.3*	0.52	-0.26	0.6*	-0.74	-0.14	-0.94	16.03*
4*5	-2.18*	0.43	-21.6*	-14.58*	0.82	0.45	-8.81*	-17.24*	0.02	6.06*	-0.5*	-0.85*	2.56*	2.31*	3.90	-15.1*
4*6	0.67	-1.26	10.4*	5.97*	-1.56*	-0.68*	-4.36*	3.31	3.27*	-2.37*	-0.25	-0.42*	-0.59	-0.99	-13.39*	-29.78*
4*7	-2.25*	-3.09*	13.92*	-7.37*	0.92	0.6*	5.22*	1.73	-2.5*	1.95*	0.44*	0.24	-0.14	1.06	62.25*	-47.24*
4*8	-2.39*	2.49*	12.5*	4.04*	0.45	0.69*	14.43*	9.27*	6.14*	5.66*	-0.83*	-0.53*	-1.69*	-0.99	6.89	29.19*
5*6	0.53	3.78*	7.49*	4.47*	0.29	-0.06	4.36*	-3.21	-6.47*	-4.94*	0.7*	0.21	-2.14*	-0.04	22.76*	3.71
5*7	-4.94*	1.15*	1.01	2.17	0.12	0.92*	6.24*	-2.29	-2.23*	-1.49*	0.04	-0.28	2.81*	3.01*	36.02*	59.65*
5*8	8.47*	-1.72*	5.08	-6.26*	-0.95*	-1.65*	-5.16*	-7.05*	-8.99*	-2.61*	-0.43*	-0.15	-4.74*	-4.54*	50.25*	18.97*
6*7	-1.89*	2.26*	-8.49*	2.43	-0.41	-0.66*	2.39*	5.26*	4.53*	4.28*	0.24	0.51*	-0.34	-0.79	-3.89	-8.80
6*8	0.47	4.34*	1.58	3.79	2.06*	1.12*	1.09	7.5*	0.22	6.49*	0.27	-0.31	-1.89*	0.66	47.96*	55.52*
7*8	1.56	-0.79	4.65	10.85*	1.2*	0.6*	28.17*	3.62	7.25*	-0.99	1.31*	0.85*	4.06*	2.21*	-63.9*	-104.47*
LSD 0.05	3.66	3.45	10.98	8.03	1.20	0.98	2.79	10.23	0.76	2.60	0.59	0.56	2.58	3.05	21.82	20.68
LSD0.05Sij-Sik	5.37	5.06	16.10	11.78	1.76	1.43	4.09	15.01	1.11	3.81	0.87	0.83	3.79	4.48	32.00	30.33
LSD0.05Sij-Skl	5.06	4.77	15.18	11.10	1.66	1.35	3.86	14.15	1.05	3.59	0.82	0.78	3.57	4.22	30.17	28.60
Sij	1.79	1.69	5.36	3.92	0.59	0.48	1.36	5	0.37	1.27	0.29	0.28	1.26	1.49	10.65	10.1

conditions, while in water stressed conditions gca effects varied from -1.59*(IS23514) to 1.56*(IS4578). The best general combiners were found to be IS40772 and IS4578 in well watered and water stressed conditions respectively. P. Anuradha found to be the best specific combiner in well watered and water stressed conditions.

The gca effects of Dry weight varied from -50.69 *(M35-1) to 26.01*(IS40752) and IS40752 found to be the best general combiner in well watered condition, while in water stressed condition gca effects varied from -23.16*(P.Anuradha) to 31.59*(IS23514) and IS23514 found to be the best general combiner. From the GGE biplot analysis, IS23514 and IS40772 were found to be the best specific combiners in well watered and water stressed conditions respectively.



GGE biplot analysis of PIYld WW



GGE biplot analysis of PIYld WS

Fig. 1 : A, a IS 40772, B,b IS 40752, C,c IS 4578, D,d IS 23514, E,e M35-1, F,f : P.Chitra, G,g P.Anuradha, F,f: CSV 22

The Study demonstrated the utility of GGE biplot analysis in identifying stable and superior genotypes. Identified parents and crosses with better specific combining abilities can be successfully be deployed in drought resistance breeding programme.

Codes and details of the genotypes used in the study:

Genotype code	Genotype name
G1	IS 40772
G2	IS 40752
G3	IS 4578
G4	IS 23514
G5	M35-1
G6	P. Chitra
G7	P. Anuradha
G8	CSV22

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