Range Mgmt. & Agroforestry 41 (2) : 218-226, 2020
ISSN 0971-2070

Identifying drought-tolerant hybrids in pearl millet [*Pennisetum glaucum* (L.) R. Br.] using stress indices for arid and semi-arid areas

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Received: 17th October, 2019 Accepted: 12th September, 2020

Abstract
The present experiment was conducted to identify F_1 hybrids suitable for drought-affected areas in pearl millet on stress indices. Fifty F_1 hybrids (which were developed at ICRISAT, Hyderabad during Summer, 2018) along with three standard checks were laid down in randomized block design with three replications in two different environments. Six stress indices *viz*., stress tolerance (TOL), stress susceptibility index (SSI), stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP) and yield index (YI) were calculated to screen the hybrids for moisture stress tolerance based on grain as well as dry stover yield (biological yield) per plant. Pooled ANOVA showed that genotype, environment and genotype x environment interaction effects were highly significant for both the characters. Genotype effect was the most important source of grain as well as dry stover yield and accounted for 52.82% and 51.12%, respectively of the total sum of squares. Mean grain yield and dry stover yield per plant of hybrids decreased under stress environment. Based on grain yield, dry stover yield and stress indices, the hybrids *viz*., ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-423, RMS 7A x BIB-407, ICMA 843-22 x BIB-451 and ICMA 88004 x BIB-423 were identified as most tolerant for moisture stress conditions and recommended for drought affected areas. These hybrids can also be used for stress breeding as well as developing moisture stress tolerant populations.

Keywords: Biological yield, Drought, Dual-purpose hybrids, Grain yield, Stress indices

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.], which is a staple food for the majority of poor farmers, is also an important fodder crop for livestock in arid and semi-arid regions of India and some other countries like Africa and Australia. It is an important coarse grain crop and serves as a staple food for the millions of people thriving under hunger. It is highly cross-pollinated and diploid and beli--eved to have originated from Africa (Vavilov, 1950). Being a C_4 plant, it has high photosynthetic efficiency and dry matter production. Plants are highly heterozygous because of its cross-pollinating nature due to protogyny. It is traditionally grown as rainfed crop mostly under low fertility and rainfall areas but also responds well to irrigation or improved management conditions. Pearl millet is mainly grown in the state of Rajasthan, Uttar Pradesh, Gujarat, Maharashtra, Haryana, Karnataka, Tamil Nadu, Madhya Pradesh and Andhra Pradesh in India.

The primary objective of any crop improvement programme is to increase the yield potential of the crop in improved management as well as adverse conditions. A successful breeding programme for yield improvement mainly depends on the nature and magnitude of variation available in materials and role played by the environment in the expression of plant characters. Moisture stress or drought is a major limiting factor in the productivity of many crops, including pearl millet. Crop inevitably suffers from moisture stress during the reproductive period of growth after depletion of stored water (Kumar, 2001). Majority of the pearl millet production is still dependent on rainfall and conserved moisture. Hence the development of drought-tolerant varieties or hybrids of pearl millet is essential to increase the production as well as productivity. In the absence of an understanding of the special mechanisms of tolerance, the quantification of moisture stress tolerance should be based on the yield in both stress and non-stress conditions that can lead to the selection of tolerant genotypes under stress condition (Kokten *et al.,* 2010). With this perspective, the present investigation was carried out to evaluate 50 single cross hybrids along with three standard checks, under moisture stress conditions, for grain yield, dry stover yield and six stress indices *viz*., stress tolerance (TOL), stress susceptibility index (SSI), stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP) and yield index (YI).

Materials and Methods

Experimental material: The experimental material for the present study consisted of 50 F_1 hybrids and three standard check hybrids (HHB 67 Improved, RHB-177 and MPMH-17). The 50 F_1 hybrids were generated using line x tester mating design at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad during Summer, 2018. The hybrids were generated by employing five male sterile lines (RMS 7A from Rajasthan Agricultural Research Institute, Jaipur, Rajasthan and ICMA 843-22, ICMA 88004, ICMA 93333 and ICMA 97111 from ICRISAT, Patancheru, Hyderabad) and ten restorers (BIB-343, BIB-359, BIB-383, BIB-391, BIB-399, BIB-407, BIB-415, BIB-423, BIB-439 and BIB-451 from AICRP on Pearl Millet, Bikaner, Rajasthan).

Environmental details: The two environments, namely E_1 and E_2, (non-stress or normal and stress environments, respectively) were created by differentiating number of irrigations. Based on the last few years meteorological data, low rainfall pattern at critical stages created the need for two different environments where under non-stress condition irrigations at critical stages like tillering, flowering and grain filling was given. In both situations, pre-sowing irrigation was given to facilitate seed germination. In E_1, three irrigations were provided at all the critical stages while in E_2, only one irrigation was provided at critical stage tillering.

Experimental details and location: The resultant hybrids along with checks were grown in randomized block design with three replications in two environments at Agricultural Research Station, Bikaner during *Kharif,* 2018. The research farm is situated between 27°1' N latitude and 71°54' E longitude at an altitude of 228.50 meters above mean sea level. This region falls under agro-climatic zone 1C of Rajasthan. The climate of the region is typically hyper-arid characterized by extreme temperature during both summer and winter and salinity of rhizosphere. The average rainfall is about 260 mm, which is mostly received during July-September. The experimental material was sown on 11 July 2018. Each plot consisted of two rows each of 4-meter length with 60 cm of row spacing and 15 cm of plant to plant spacing. All recommended cultural practices were followed to raise good crop except irrigation. The irrigation was provided by sprinkler system till the soil get saturated at the level of sowing depth or root zone, and the exact quantity of water was not measured.

Observations: The observations were recorded on grain yield per plant (g) and dry stover yield or biological yield per plant (g) in both the environments and used to calculate different stress indices. The earheads of the ten tagged plants were threshed together, weighed and averaged to obtain grain yield per plant. The ten randomly selected and tagged plant's above-ground parts were dried in sunlight and weighed in grams and averaged to calculate dry stover yield per plant. Since the observations recorded on the above traits in environments described earlier were sufficient for calculation of stress indices, the experiment was terminated after only one season.

Stress indices and statistical analysis: The following six moisture stress tolerance indices were calculated using the following formulae:

- Stress tolerance (TOL) = $Y_p - Y_s$ (Rosielle and Hamblin, 1981). The hybrids with low values of this index were more stable in two different environments.
- Stress susceptibility index (SSI) = $[1 - (Y_s / Y_p)] / [1 - (\bar{Y}_s / _p)]$ (Fischer and Maurer, 1978). The hybrids with SSI< 1 were more resistant to moisture stress.
- Stress tolerance index (STI) = $(Y_p)(Y_s)/(\bar{Y}_p)^2$ (Fernandez, 1992). The hybrids with high STI values were tolerant to moisture stress.
- Mean productivity (MP) = $(Y_s + Y_p)/2$ (Rosielle and Hamblin, 1981). The hybrids with high value of this index were desirable.
- Geometric mean productivity (GMP) = $\sqrt{Y_s \times Y_p}$ (Fernandez, 1992). The hybrids with high value of this index were desirable.
- Yield index (YI) = $(Y_s)/(\bar{Y}_s)$ (Gavuzzi *et al*. 1997). The hybrids with a high value of this index were suitable for stress condition.

Where, Y_s and Y_p represent grain yield or biological yield per plant (g) for each hybrid in stress and non-stress conditions, respectively and $\bar{Y}_s$ and $\bar{Y}_p$ are mean grain yield or biological yield per plant in stress and non-stress conditions, respectively for all the hybrids (53). The mean data for grain as well as dry stover or biological yield per plant were subjected to analysis of variance following Panse and Sukhatme (1985). Ranks were assigned to each hybrid for each index. Based on indices formula, the hybrid with the highest value for Y_s, Y_p, MP, GMP, STI and YI and the lowest value for SSI and TOL received a rank 1^{st}.

Results and Discussion

Pooled analysis: The pooled analys is of variance for

Table 1. The pooled analysis of variance for grain and dry stover yields of hybrids tested across non-stress (E_1) and stress (E_2) conditions

Source of variation	Grain yield per plant (g)				Dry stover yield per plant (g)			
	df	SS	MSS	% TSS	df	SS	MSS	% TSS
Genotype (G)	52	6106.73	117.437**	52.82	52	27314.51	525.279**	51.12
Environment (E)	1	2054	2054.000**	17.77	1	5484.06	5484.060**	10.26
Replication within environment	4	107.11	26.778	0.93	4	518.37	129.593	0.97
G x E	52	947.46	18.220**	8.2	52	5281.86	101.574*	9.88
Error	208	2345.02	11.274	20.29	208	14834.64	71.320	27.76
Total	317	11560.32		100.00	317	53433.44		100.00

*(P<0.05); **(P<0.01)

grain yield per plant and dry stover yield per plant over two environments was recorded (Table 1). The mean sum of squares due to genotypes, environments and genotype x environment interaction were found significant for both the characters. The genotype effect was the most important source of grain yield as well as dry stover yield variation which accounted for 52.82% and 51.12%, respectively of the total sum of squares (TSS) followed by environment and genotype x environment interaction effects. This indicated the differential response of hybrids to moisture stress for grain yield and dry stover yield per plant.

Mean performance of hybrids

Grain yield per plant: The mean grain yield per plant in non-stress condition (Y_p) was 13.75 g and ranged from 7.22 g (ICMA 93333 x BIB-407) to 27.20 g (ICMA 843-22 x BIB-343) while in stress condition (Y_s) it was 8.66 g and ranged from 4.65 g (ICMA 97111 x BIB-383) to 22.52 g (ICMA 843-22 x BIB-343). Thus the data indicated that the mean grain yield decreased under stress. Hybrids namely, ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-451 and RMS 7A x BIB-407 were recorded highest grain yield per plant, respectively in non-stress condition (E_1). Whereas hybrids ICMA 843-22 x BIB-343, RMS 7A x BIB-407 and ICMA 843-22 x BIB-451 obtained the highest grain yield per plant, respectively in stress condition (E_2) (Table 2).

Dry stover or biological yield per plant: The mean dry stover per plant yield in non-stress condition (Y_p) was 38.01 g and ranged from 23.05 g (ICMA 97111 x BIB-343) to 62.98 g (ICMA 843-22A x BIB-359, while in stress condition (Y_s) it was 29.70 g and ranged from 22.75 g (ICMA 88004 x BIB-407) to 52.21 g (ICMA 843-22A x BIB-343). Thus the data indicated that the mean dry stover or biological yield decreased under stress. Hybrids namely, ICMA 843-22A x BIB-359, ICMA 843-22A x BIB-407 and RMS 7A x BIB-343 were recorded highest dry stover yield per plant in non-stress condition (E_1). Whereas hybrids ICMA 843-22A x BIB-343, RMS 7A x BIB-407 and RMS 7A x BIB-343 obtained highest dry stover yield per plant in stress condition (E_2) (Table 3).

Stress indices

Grain yield per plant: To evaluate moisture stress-tolerant hybrids using TOL index, a higher value of TOL demonstrated more changes of hybrid yield in stress and non-stress conditions and showed the susceptibility to the non-stress condition. The results of the present experiment revealed that hybrids ICMA 97111 x BIB-343 showed the lowest value of TOL and ranked first followed by ICMA 88004 x BIB-359, ICMA 843-22 x BIB-439, ICMA 93333 x BIB-407 and RMS 7A x BIB-439 with respect to high moisture stress tolerance ability. For SSI, the higher value refers to more susceptible to stress. Therefore, the hybrid ICMA 97111 x BIB-343 ranked first followed by ICMA 88004 x BIB-359, ICMA 843-22 x BIB-439, RMS 7A x BIB-439 and ICMA 93333 x BIB-407. The mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) also showed a similar ranking of hybrids for moisture stress tolerance (Table 2). The stress tolerance index (STI) was used to identify hybrids that produced high yields under both stress and normal conditions. The larger the value of STI for a hybrid, the higher was its tolerance to stress. The cross ICMA 843-22 x BIB-343 had the highest value of STI which indicated its high tolerance to moisture stress followed by ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-451, ICMA 843-22 x BIB-423 and ICMA 88004 x BIB-423. Similar results were also reported for MP and GMP. Based on YI, hybrids ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-451, RMS 7A x BIB-407, ICMA 843-22 x BIB-423 and ICMA 88004 x BIB-423 had the highest YI and Ys, hence these were more tolerant to moisture stress. Based on the present study, it was recorded that MP, GMP and STI values were handy attributes in selecting high yielding genotypes under both stress and non-stress conditions, while the relative decrease in yield, TOL and SSI values were better indices to establish tolerance levels.

Table 2. Grain yield per plant and moisture stress indices in response to normal (E_1) and moisture stress (E_2) conditions

Hybrids	Grain yield per plant				TOL		SSI		STI		MP		GMP		YI			
	(Y_p)	R	(Y_s)	R	V	R	V	R	V	R	V	R	V	R	V	R	S_R	R_O
RMS 7A x BIB-343	21.70	8	11.19	6	10.51	49	1.31	38	1.29	6	16.45	6	15.58	6	1.29	6	125	8
RMS 7A x BIB-359	10.95	31	5.87	47	5.08	30	1.25	36	0.34	39	8.41	37	8.02	39	0.68	47	306	44
RMS 7A x BIB-383	16.27	14	10.11	7	6.16	37	1.02	28	0.87	10	13.19	11	12.83	10	1.17	7	124	7
RMS 7A x BIB-391	13.34	22	6.65	38	6.69	41	1.36	39	0.47	29	10.00	27	9.42	29	0.77	38	263	37
RMS 7A x BIB-399	10.63	34	8.02	22	2.61	17	0.66	19	0.45	30	9.33	30	9.23	30	0.93	22	204	24
RMS 7A x BIB-407	25.41	3	20.27	2	5.14	31	0.55	14	2.73	3	22.84	3	22.69	3	2.34	2	61	3
RMS 7A x BIB-415	17.57	12	7.42	33	10.15	48	1.56	48	0.69	16	12.50	15	11.42	16	0.86	33	221	30
RMS 7A x BIB-423	18.75	10	7.56	30	11.19	50	1.61	52	0.75	14	13.16	12	11.91	14	0.87	30	212	27
RMS 7A x BIB-439	9.14	44	8.03	21	1.11	5	0.33	4	0.39	33	8.59	35	8.57	33	0.93	21	196	22
RMS 7A x BIB-451	22.67	6	9.33	11	13.34	52	1.59	50	1.12	7	16.00	7	14.54	7	1.08	11	151	11
ICMA 843-22 x BIB-343	27.20	1	22.52	1	4.68	25	0.47	11	3.24	1	24.86	1	24.75	1	2.60	1	42	1
ICMA 843-22 x BIB-359	12.60	23	7.66	28	4.94	29	1.06	30	0.51	24	10.13	25	9.82	24	0.88	28	211	26
ICMA 843-22 x BIB-383	18.25	11	8.46	18	9.79	47	1.45	46	0.82	11	13.36	10	12.43	11	0.98	18	172	17
ICMA 843-22 x BIB-391	11.62	27	8.36	19	3.26	21	0.76	23	0.51	23	9.99	28	9.86	23	0.97	19	183	19
ICMA 843-22 x BIB-399	15.48	17	7.42	33	8.06	44	1.41	43	0.61	19	11.45	17	10.72	19	0.86	33	225	31
ICMA 843-22 x BIB-407	21.43	9	8.71	15	12.72	51	1.61	51	0.99	8	15.07	8	13.66	8	1.01	15	165	16
ICMA 843-22 x BIB-415	14.63	19	7.94	23	6.69	42	1.24	35	0.61	17	11.29	18	10.78	17	0.92	23	194	21
ICMA 843-22 x BIB-423	24.14	4	19.65	4	4.49	24	0.50	12	2.51	4	21.90	4	21.78	4	2.27	4	60	2
ICMA 843-22 x BIB-439	9.46	41	8.57	17	0.89	3	0.25	3	0.43	31	9.02	31	9.00	31	0.99	17	174	18
ICMA 843-22 x BIB-451	25.93	2	20.07	3	5.86	34	0.61	17	2.75	2	23.00	2	22.81	2	2.32	3	65	4
ICMA 88004 x BIB-343	9.30	42	7.51	31	1.79	10	0.52	13	0.37	36	8.41	38	8.36	36	0.87	31	237	34
ICMA 88004 x BIB-359	9.94	38	9.15	13	0.79	2	0.21	2	0.48	28	9.55	29	9.54	28	1.06	13	153	12
ICMA 88004 x BIB-383	10.80	33	5.25	51	5.55	32	1.39	41	0.30	47	8.03	41	7.53	47	0.61	51	343	50
ICMA 88004 x BIB-391	16.04	15	9.49	10	6.55	39	1.10	32	0.81	12	12.77	13	12.34	12	1.10	10	143	10
ICMA 88004 x BIB-399	11.41	29	9.50	9	1.91	12	0.45	10	0.57	21	10.46	22	10.41	21	1.10	9	133	9
ICMA 88004 x BIB-407	7.54	51	6.38	41	1.16	6	0.42	8	0.25	51	6.96	51	6.94	51	0.74	41	300	42
ICMA 88004 x BIB-415	8.77	48	7.59	29	1.18	7	0.36	6	0.35	37	8.18	40	8.16	37	0.88	29	233	33

Hybrids	Grain yield per plant				TOL		SSI		STI		MP		GMP		YI			
	(Y_p)	R	(Y_s)	R	V	R	V	R	V	R	V	R	V	R	V	R	S_R	R_O
ICMA 88004 x BIB-423	23.12	5	17.07	5	6.05	36	0.71	20	2.09	5	20.10	5	19.87	5	1.97	5	86	5
ICMA 88004 x BIB-439	17.17	13	8.18	20	8.99	46	1.42	44	0.74	15	12.68	14	11.85	15	0.94	20	187	20
ICMA 88004 x BIB-451	9.20	43	6.05	44	3.15	20	0.93	26	0.29	48	7.63	50	7.46	48	0.70	44	323	48
ICMA 93333 x BIB-343	13.81	20	6.74	37	7.07	43	1.38	40	0.49	26	10.28	23	9.65	26	0.78	37	252	36
ICMA 93333 x BIB-359	10.07	35	7.16	35	2.91	19	0.78	24	0.38	34	8.62	34	8.49	34	0.83	35	250	35
ICMA 93333 x BIB-383	13.37	21	8.62	16	4.75	26	0.96	27	0.61	18	11.00	19	10.74	18	1.00	16	161	15
ICMA 93333 x BIB-391	9.06	45	6.54	40	2.52	16	0.75	22	0.31	43	7.80	46	7.70	43	0.75	40	295	40
ICMA 93333 x BIB-399	9.80	39	5.91	45	3.89	22	1.07	31	0.31	46	7.86	44	7.61	46	0.68	45	318	47
ICMA 93333 x BIB-407	7.22	53	6.29	42	0.93	4	0.35	5	0.24	52	6.76	52	6.74	52	0.73	42	302	43
ICMA 93333 x BIB-415	10.05	37	5.27	49	4.78	28	1.29	37	0.28	49	7.66	49	7.28	49	0.61	49	347	51
ICMA 93333 x BIB-423	10.06	36	5.91	45	4.15	23	1.12	33	0.31	42	7.99	42	7.71	42	0.68	45	308	46
ICMA 93333 x BIB-439	22.45	7	7.51	31	14.94	53	1.80	53	0.89	9	14.98	9	12.98	9	0.87	31	202	23
ICMA 93333 x BIB-451	12.45	24	7.69	27	4.76	27	1.03	29	0.51	25	10.07	26	9.78	25	0.89	27	210	25
ICMA 97111 x BIB-343	8.09	50	7.80	25	0.29	1	0.10	1	0.33	40	7.95	43	7.94	40	0.90	25	225	31
ICMA 97111 x BIB-359	7.51	52	4.99	52	2.52	15	0.91	25	0.20	53	6.25	53	6.12	53	0.58	52	355	52
ICMA 97111 x BIB-383	10.90	32	4.65	53	6.25	38	1.55	47	0.27	50	7.78	48	7.12	50	0.54	53	371	53
ICMA 97111 x BIB-391	11.11	30	5.26	50	5.85	33	1.42	45	0.31	45	8.19	39	7.64	45	0.61	50	337	49
ICMA 97111 x BIB-399	11.67	26	9.82	8	1.85	11	0.43	9	0.61	20	10.75	20	10.71	20	1.13	8	122	6
ICMA 97111 x BIB-407	8.73	49	6.96	36	1.77	9	0.55	15	0.32	41	7.85	45	7.79	41	0.80	36	272	38
ICMA 97111 x BIB-415	11.69	25	5.65	48	6.04	35	1.40	42	0.35	38	8.67	33	8.13	38	0.65	48	307	45
ICMA 97111 x BIB-423	14.95	18	6.21	43	8.74	45	1.58	49	0.49	27	10.58	21	9.64	27	0.72	43	273	39
ICMA 97111 x BIB-439	9.03	46	7.81	24	1.22	8	0.37	7	0.37	35	8.42	36	8.40	35	0.90	24	215	28
ICMA 97111 x BIB-451	8.97	47	6.60	39	2.37	14	0.71	21	0.31	44	7.79	47	7.69	44	0.76	39	295	40
HHB 67 Improved	11.58	28	8.83	14	2.75	18	0.64	18	0.54	22	10.21	24	10.11	22	1.02	14	160	14
RHB-177	15.78	16	9.19	12	6.59	40	1.13	34	0.77	13	12.49	16	12.04	13	1.06	12	156	13
MPMH-17	9.75	40	7.75	26	2.00	13	0.55	16	0.40	32	8.75	32	8.69	32	0.89	26	217	29
Overall mean	**13.75**		**8.66**															

Where Y_p and Y_s= grain yield per plant under non-stress (E_1) and stress (E_2) conditions, V and R= Value and rank of the concerned index for concerned hybrid, and S_R and R_O= Rank sum and an overall rank of concerned hybrids, respectively

Table 3. Dry stover yield per plant and moisture stress indices in response to normal (E_1) and moisture stress (E_2) conditions

Hybrids	Dry stover yield per plant				TOL		SSI		STI		MP		GMP		YI			
	(Y_p)	R	(Y_s)	R	V	R	V	R	V	R	V	R	V	R	V	R	S_R	R_O
RMS 7A x BIB-343	61.89	3	44.8	3	17.09	44	1.26	34	1.92	2	53.35	2	52.66	2	1.51	3	143	5
RMS 7A x BIB-359	27.68	40	24.58	42	3.1	19	0.51	19	0.47	41	26.13	41	26.08	41	0.83	42	386	39
RMS 7A x BIB-383	44.31	17	26.02	30	18.29	45	1.89	50	0.80	19	35.17	19	33.96	19	0.88	30	321	30
RMS 7A x BIB-391	60.63	5	35.88	10	24.75	52	1.87	48	1.51	7	48.26	7	46.64	7	1.21	10	213	10
RMS 7A x BIB-399	49.92	10	34.56	12	15.36	43	1.41	38	1.19	12	42.24	12	41.54	12	1.16	12	216	11
RMS 7A x BIB-407	59.04	7	52.18	2	6.86	29	0.53	20	2.13	1	55.61	1	55.50	1	1.76	2	101	2
RMS 7A x BIB-415	49.82	11	28.85	17	20.97	47	1.93	52	0.99	15	39.34	16	37.91	15	0.97	17	265	18
RMS 7A x BIB-423	45.59	15	26.95	23	18.64	46	1.87	49	0.85	18	36.27	18	35.05	18	0.91	23	294	24
RMS 7A x BIB-439	59.79	6	34.87	11	24.92	53	1.91	51	1.44	9	47.33	8	45.66	9	1.17	11	228	13
RMS 7A x BIB-451	61.43	4	40.18	7	21.25	48	1.58	42	1.71	6	50.81	5	49.68	6	1.35	7	184	8
ICMA 843-22 x BIB-343	48.83	12	52.21	1	-3.38	1	-0.32	4	1.76	3	50.52	6	50.49	3	1.76	1	45	1
ICMA 843-22 x BIB-359	62.98	1	39.69	9	23.29	51	1.69	46	1.73	5	51.34	3	50.00	5	1.34	9	190	9
ICMA 843-22 x BIB-383	50.33	9	28.4	19	21.93	50	1.99	53	0.99	16	39.37	15	37.81	16	0.96	19	275	19
ICMA 843-22 x BIB-391	27.93	39	25.75	32	2.18	16	0.36	16	0.50	37	26.84	37	26.82	37	0.87	32	333	33
ICMA 843-22 x BIB-399	48.31	13	34.53	13	13.78	39	1.31	35	1.15	13	41.42	13	40.84	13	1.16	13	217	12
ICMA 843-22 x BIB-407	61.94	2	40.44	6	21.5	49	1.59	43	1.73	4	51.19	4	50.05	4	1.36	6	175	7
ICMA 843-22 x BIB-415	34.08	27	28.64	18	5.44	24	0.73	24	0.68	23	31.36	23	31.24	23	0.96	18	249	17
ICMA 843-22 x BIB-423	44.28	18	42.73	5	1.55	14	0.16	14	1.31	10	43.51	10	43.50	10	1.44	5	123	4
ICMA 843-22 x BIB-439	31.77	31	25.58	34	6.19	27	0.89	27	0.56	30	28.68	31	28.51	30	0.86	34	336	34
ICMA 843-22 x BIB-451	44.05	19	42.93	4	1.12	13	0.12	12	1.31	11	43.49	11	43.49	11	1.45	4	121	3
ICMA 88004 x BIB-343	25.65	45	27.17	21	-1.52	5	-0.27	6	0.48	38	26.41	39	26.40	38	0.91	21	284	20
ICMA 88004 x BIB-359	28.02	38	24.42	45	3.6	20	0.59	21	0.47	40	26.22	40	26.16	40	0.82	45	392	46
ICMA 88004 x BIB-383	32.14	30	26.33	28	5.81	26	0.83	26	0.59	27	29.24	28	29.09	27	0.89	28	304	26
ICMA 88004 x BIB-391	26.41	43	24.2	47	2.21	17	0.38	18	0.44	47	25.31	46	25.28	47	0.81	47	419	52
ICMA 88004 x BIB-399	28.77	37	26.47	27	2.3	18	0.37	17	0.53	34	27.62	35	27.60	34	0.89	27	311	27
ICMA 88004 x BIB-407	36.23	25	22.75	53	13.48	38	1.70	47	0.57	29	29.49	27	28.71	29	0.77	53	417	51
ICMA 88004 x BIB-415	24.47	48	26.64	26	-2.17	3	-0.41	2	0.45	45	25.56	45	25.53	45	0.90	26	317	28

Hybrids	Dry stover yield per plant				TOL		SSI		STI		MP		GMP		YI		S_R	R_O
	(Y_p)	R	(Y_s)	R	V	R	V	R	V	R	V	R	V	R	V	R		
ICMA 88004 x BIB-423	52.34	8	39.94	8	12.4	35	1.08	31	1.45	8	46.14	9	45.72	8	1.34	8	166	6
ICMA 88004 x BIB-439	37.28	23	24.57	43	12.71	36	1.56	41	0.63	24	30.93	24	30.26	24	0.83	43	360	35
ICMA 88004 x BIB-451	27.35	41	27.06	22	0.29	10	0.05	10	0.51	36	27.21	36	27.20	36	0.91	22	286	21
ICMA 93333 x BIB-343	30.10	34	25.96	31	4.14	22	0.63	23	0.54	32	28.03	33	27.95	32	0.87	31	325	31
ICMA 93333 x BIB-359	34.69	26	23.26	51	11.43	34	1.51	40	0.56	31	28.98	29	28.41	31	0.78	51	404	48
ICMA 93333 x BIB-383	41.35	20	26.09	29	15.26	42	1.69	44	0.75	21	33.72	21	32.85	21	0.88	29	318	29
ICMA 93333 x BIB-391	24.32	49	27.38	20	-3.06	2	-0.58	1	0.46	44	25.85	44	25.80	44	0.92	20	295	25
ICMA 93333 x BIB-399	23.82	51	24.99	37	-1.17	7	-0.22	7	0.41	52	24.41	52	24.40	52	0.84	37	390	43
ICMA 93333 x BIB-407	30.93	33	26.92	24	4.01	21	0.59	22	0.58	28	28.93	30	28.86	28	0.91	24	288	22
ICMA 93333 x BIB-415	48.06	14	33.02	14	15.04	41	1.43	39	1.10	14	40.54	14	39.84	14	1.11	14	233	14
ICMA 93333 x BIB-423	24.86	47	24.90	40	-0.04	9	-0.01	9	0.43	49	24.88	49	24.88	49	0.84	40	388	42
ICMA 93333 x BIB-439	44.89	16	31.78	15	13.11	37	1.34	37	0.99	17	38.34	17	37.77	17	1.07	15	239	15
ICMA 93333 x BIB-451	37.94	22	23.91	49	14.03	40	1.69	45	0.63	25	30.93	25	30.12	25	0.80	49	391	44
ICMA 97111 x BIB-343	23.05	53	24.51	44	-1.46	6	-0.29	5	0.39	53	23.78	53	23.77	53	0.83	44	414	50
ICMA 97111 x BIB-359	24.10	50	25.13	36	-1.03	8	-0.20	8	0.42	50	24.62	51	24.61	50	0.85	36	383	38
ICMA 97111 x BIB-383	25.59	46	24.95	39	0.64	11	0.11	11	0.44	48	25.27	48	25.27	48	0.84	39	386	39
ICMA 97111 x BIB-391	23.63	52	25.61	33	-1.98	4	-0.38	3	0.42	51	24.62	50	24.60	51	0.86	33	366	36
ICMA 97111 x BIB-399	28.91	36	23.99	48	4.92	23	0.78	25	0.48	39	26.45	38	26.34	39	0.81	48	403	47
ICMA 97111 x BIB-407	25.70	44	24.87	41	0.83	12	0.15	13	0.44	46	25.29	47	25.28	46	0.84	41	387	41
ICMA 97111 x BIB-415	31.12	32	24.28	46	6.84	28	1.01	29	0.52	35	27.70	34	27.49	35	0.82	46	391	44
ICMA 97111 x BIB-423	28.95	35	23.16	52	5.79	25	0.92	28	0.46	43	26.06	42	25.89	43	0.78	52	432	53
ICMA 97111 x BIB-439	32.95	29	23.55	50	9.4	32	1.31	36	0.54	33	28.25	32	27.86	33	0.79	50	406	49
ICMA 97111 x BIB-451	27.07	42	24.97	38	2.1	15	0.36	15	0.47	42	26.02	43	26.00	42	0.84	38	370	37
HHB 67 Improved	38.43	21	29.38	16	9.05	31	1.08	30	0.78	20	33.91	20	33.60	20	0.99	16	242	16
RHB-177	37.10	24	26.86	25	10.24	33	1.26	33	0.69	22	31.98	22	31.57	22	0.90	25	288	22
MPMH-17	33.65	28	25.51	35	8.14	30	1.11	32	0.59	26	29.58	26	29.30	26	0.86	35	331	32
Overall mean	**38.01**		**29.70**															

Where Y_p and Y_s= dry stover or biological yield per plant under non-stress (E_1) and stress (E_2) conditions, V and R= Value and rank of the concerned index for concerned hybrid, and S_R and R_O= Rank sum and an overall rank of concerned hybrids, respectively

Dry stover or biological yield per plant: The hybrid ICMA 843-22 x BIB-343 showed the lowest value of TOL and ranked first followed by ICMA 93333 x BIB-391, ICMA 88004 x BIB-415, ICMA 97111 x BIB-391 and ICMA 88004 x BIB-343 with respect to high moisture stress tolerance ability. For SSI, the hybrid ICMA 93333 x BIB-391 ranked first followed by ICMA 88004 x BIB-415, ICMA 97111 x BIB-391, ICMA 843-22 x BIB-343 and ICMA 97111 x BIB-343. The mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) also showed a similar ranking of hybrids for moisture stress tolerance (Table 3). The larger the value of STI for a hybrid, the higher was its tolerance to stress. The cross RMS 7A x BIB-407 had the highest value of STI which indicated its high tolerance to moisture stress followed by RMS 7A x BIB-343, ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-407 and ICMA 843-22 x BIB-359. Similar results were also observed for MP and GMP. Based on YI, hybrids ICMA 843-22 x BIB-343, RMS 7A x BIB-407, RMS 7A x BIB-343, ICMA 843-22 x BIB-451 and ICMA 843-22 x BIB-423 had the highest YI and Ys, hence more tolerant to moisture stress. Thus the present study revealed that MP, GMP and STI values were convenient parameters to select high yielding genotypes in both stress and non-stress conditions. In contrast, the relative decrease in yield, TOL and SSI values were better indices to determine tolerance levels.

Selection criteria for moisture stress-tolerant hybrids

The estimated values of moisture stress tolerance indices (Table 2-3) indicated that the identification of moisture stress-tolerant genotypes based on a single criterion (index) was contradictory. Different indices introduced different hybrids as moisture stress-tolerant. Therefore, to determine the most desirable moisture stress tolerant hybrid based on all indices, the ranking was done, and moisture stress-tolerant hybrids were identified. A hybrid with least rank total was considered to be the best hybrid. According to this criteria hybrids ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-423, RMS 7A x BIB-407, ICMA 843-22 x BIB-451 and ICMA 88004 x BIB-423 were identified as the most tolerant for moisture stress conditions. The highest tolerant check was RHB 177, which recorded rank 14 for grain yield and HHB 67 Improved for dry stover yield recorded rank 16. Such strategies of using different tolerance indices and ranking pattern for the screening of tolerant genotypes were used by several other workers earlier in different crops (Kharrazi and Rad, 2011; Kiani, 2013; Rajarajan and Ganesamurthy, 2014; Abraha *et al.,* 2015; Kumawat *et al.,* 2017; Sah *et al.,* 2017; Anita *et al.,* 2018; El-Sabagh *et al.,* 2018).

Grain iron and zinc content of superior hybrids

Only the top five superior hybrids over the best check were tested for grain iron (Fe), and zinc (Zn) content at ICRISAT, Hyderabad (Table 4). It was observed that hybrid RMS 7A x BIB-407 had maximum grain iron (65) as well as zinc (69) contents (ppm). Indeed, deficiencies of essential micro-nutrients such as iron and zinc are the cause of extensive health problems in developing countries like India (Manwaring *et al.*, 2016). Govindaraj *et al.* (2016) also recorded improvement on iron and zinc contents in grains of pearl millet.

Table 4. The grain iron (Fe) and zinc (Zn) content of top five hybrids over the best check for grain yield per plant

Hybrid	Iron (ppm)	Zinc (ppm)
ICMA 843-22 x BIB-343	51	44
ICMA 843-22 x BIB-451	58	55
RMS 7A x BIB-407	65	69
ICMA 843-22 x BIB-423	37	35
ICMA 88004 x BIB-423	50	45

Conclusion

Based on different moisture stress tolerance indices, hybrids namely, ICMA 843-22 x BIB-343, ICMA 843-22 x BIB-423, RMS 7A x BIB-407, ICMA 843-22 x BIB-451 and ICMA 88004 x BIB-423 were identified as most tolerant for moisture stress conditions. Therefore, these hybrids can be used for dual purpose (higher grain and biological yields) in drought-affected areas. These can also be used as a parent for hybridization programmes for moisture stress tolerance breeding as well as developing moisture stress tolerant populations in pearl millet.

Acknowledgement

The authors thank the staff of College of Agriculture, Bikaner, Agricultural Research Station, Bikaner and ICRISAT, Hyderabad for providing experimental materials as well as facilities for generating and evaluation of materials.

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