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Selection of Stable Drought Tolerant Genotypes in Finger Millet [*Eleusine coracana* (L.) Gaertn] using Combination of Drought Tolerance Indices

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Abstract

Drought stress may continue to be a major limitation for the crop productivity world wide and severity may increase with the changing climate scenario. Although the finger millet is renowned for its drought tolerance, drought stress at reproductive stage dramatically affects the grain yield. A field experiment was conducted over the two years during summer 2019 and summer 2020 to identify stable drought tolerant finger millet genotypes. Three hundred and fifty genotypes representing wide genetic variability available in finger millet were evaluated for grain yield per plant under drought stress and well watered conditions by following augmented design. Significant yield reduction was observed due to drought stress in both the years. The grain yield per plant under drought stress and well watered conditions were used to determine different drought tolerance indices (DTI) *viz.* geometric mean productivity (GMP), mean productivity (MP), harmonic mean (HM), drought resistance index (DRI), yield index (YI), yield stability index (YSI) for each genotype and year. The combination of drought tolerance indices over the two years were used to identify the stable drought tolerant genotypes. The genotypes *viz.* GE-1234, GE-1286 and GE-3003 were found to be the most drought tolerant across DTI and GE-1641, GE-4719 and GE-3722 were found to be highly susceptible. The tolerant genotypes recorded less than 26 per cent yield reduction under drought stress over the two years. On the other hand, the yield reduction was more than 76 per cent over the two years in susceptible genotypes. In the present study using combination of DTI, contrasting genotypes for drought tolerance were identified and were confirmed by yield reduction under stress environment for further use.

Keywords: Finger millet, Drought indices, Grain yield, Tolerant genotypes

Finger millet [*Eleusine coracana* (L.) Gaertn] is an important food crop in the arid zones of Africa and South Asia. In India, it is cultivated in an area of 1.19 million hectares with a production of 1.98 million tonnes and productivity of 1661 kg per hectare. Karnataka accounts for 56.21 per cent of area and 59.52 per cent of production in India (Sakamma *et al*., 2018). It is the third most important millet after sorghum and pearl millet in India. Finger millet is mainly grown under rainfed conditions in India and South Asia where drought stress for 15 to 30 days is a common feature and will remain a major abiotic limitation for productivity. Drought stress for 25 to 30 days invariably occurs during either stage of crop growth every year and decreases the grain yield significantly in finger millet (Maqsood & Azam Ali, 2007 and Anonymous, 2011). The simulation models predict that drought stress reduces the grain yield of wheat and maize by 21 to 40 per cent (Daryanto *et al*., 2016). It is predicted that moisture stress will increase in most arid and semi-arid regions of the world under future climate-change scenarios (Wassmann *et al.,* 2009) significantly affecting the crop productivity in these regions.

The rainfall pattern in the semi-arid conditions of ragi growing areas is unpredictable and intermittent drought stress occurs at all the growth stages of the crop. However, it is reported that the reproductive and gain filling stages are the most sensitive to moisture stress reducing the yield significantly (Talwar *et al.,* 2020). Achieving a yield increase and stability under drought environment has been recognized to be a difficult challenge, while progress in yield has been much higher in favorable environments (Richards *et al.,* 2002). Drought tolerance is a complex trait influenced by combinations of physiological and productivity related traits (Tuberosa, 2012). The relative yield performance of genotypes in drought and non-stress environments appear to be a common starting point for identifying desirable genotypes for unpredictable conditions (Mohammadi *et al*., 2012 and Nouri *et al.,* 2011). However, many methods of determination of drought tolerance indices (DTIs) have been proposed to identify drought tolerant genotypes in different crops. The commonly used drought tolerance indices are mean productivity (MP), yield stability index (YSI), geometric mean productivity (GMP), yield index (YI), harmonic mean (HM) and drought resistance index (DRI) to identify drought tolerant genotypes under stress conditions (Mau *et al*., 2019 and Ferede *et al*., 2020). In the present study an attempt has been made to identify finger millet genotypes tolerant to reproductive stage moisture stress by evaluating diverse genotypes over two years under drought stress and well watered conditions.

Material and Methods

Three hundred and fifty diverse genotypes of finger millet representing wide diversity were selected for the present study. The genotypes were grown at the experimental field of Department of Plant Biotechnology, UAS, GKVK, Bengaluru over the two years *viz.* Summer 2019 and Summer 2020. Each year the genotypes were grown in two main blocks separately in augmented design. One block was subjected to drought stress (DS) and another was without any stress or well watered (WW). The seedlings raised in small pots in greenhouse and 21 days old seedlings of 350 genotypes along with checks were transplanted in the field by following augmented design. Each genotype was grown in a

Table 1

Different drought tolerance indices used in the present study

Drought indices	Formula	Description	Reference
Geometric Mean Productivity (GMP)	GMP = √(Yp *Ys)	The genotypes with high value of this index will be more desirable	Schneider *et al.,* 1997
Mean Productivity (MP)	MP = Ys + Yp/2	The genotypes with high value of this index will be more desirable	Rosielle and Hamblin ,1981
Harmonic Mean (HM)	HM = 2 (Yp*Ys) / (Yp+Ys)	The genotypes with high value of this index will be more desirable	Jafari *et al.,* 2012
Drought Resistance Index (DRI)	DRI = Ys (Ys/Yp)/Yp~	The genotypes with high value of this index will be suitable for drought stress condition	Lan, 1998
Yield Index (YI)	YI = Ys/Ys~	The genotypes with high value of this index will be suitable for drought stress condition	Gavuzzi *et al.,*1997
Yield Stability Index (YSI)	YSI = Ys/Yp	The genotypes with high values can be regarded as stable genotypes under stress and non-stress conditions	Bouslama and Schapaugh,1984

Ys: grain yield under DS for each genotype and Yp: grain yield under WW for each genotype Ys~: average yield of all genotypes under DS and Yp~: average yield of all genotypes under WW single row of 1.2 m length by maintaining a spacing of 30 cm x 10 cm (row to row and plant to plant within a row, respectively). The drought stress was imposed to one block by with holding water for 20 days from 57th day after sowing. After 20 days of stress, regular irrigation was provided till the maturity for the stress block. The other block was watered regularly once in two days which served as well watered / no stress (WW). The crop was raised by following all the cultural practices including fertilizer and pesticide applications. In each block five plants each per genotype were selected for recording observations on grain yield per plant after harvest in both the years.

Data Analysis

The analysis of variance (ANOVA) by following augmented design using the mean grain yield per plant values of genotypes was carried out for stress and well watered block separately for each year. Further, the mean grain yield per plant of DS and WW block of each genotype was used to determine the different drought tolerance indices (DTI) of genotypes as given in Table 1.

For each DTI the overall mean (μ) and standard deviation (σ) was determined for each year separately and the genotypes were grouped as given below:

DTI value of a genotype	Group
$\mu + 2\sigma$ and above	- Tolerant
$\mu + \sigma$ to $\mu + 2\sigma$	- Moderately tolerant
$\mu + \sigma$ to $\mu - \sigma$	- Moderately susceptible
$\mu - \sigma$ to $\mu - 2\sigma$	- Susceptible
$\mu - 2\sigma$ and less	- Highly susceptible

The tolerant and highly susceptible genotypes for drought stress were identified for each of the DTI for both the years separately. The genotype which falls in tolerant group at least in two different DTI in each year over two years was considered as stable tolerant genotype. Similarly, the genotype which falls in highly susceptible group at least in two different drought tolerant indices over two years was considered as stable drought susceptible genotype.

Results and Discussion

Drought tolerance is a complex trait and the lack of fast reproducible screening technique based on a reliable inheritable trait linked to drought tolerance remains a challenge to identify tolerant genotype under unpredictable drought stress conditions. Several studies on drought tolerance have frequently used indirect selection indicators such as morphological and physiological responses (Kumar *et al*., 2015 and Purbajanti *et al*., 2017). Such indirect selection methods relay on many characters that need to be evaluated and the selected tolerant genotypes may not necessarily be stable for yield *per se* under stress conditions. So there is no reliable trait linked to drought tolerance not only in finger millet but also in other crops. For this reason, selection for drought tolerance based on indices developed from grain yield is considered a more rapid and effective approach for selecting drought tolerant genotypes.

The analysis of variance for grain yield per plant revealed significant mean sum of squares attributable to 'Genotypes' and 'Checks *vs.* Genotypes' under both WW and DS conditions in both the two years, indicating considerable amount of variability in the experimental material (Table 2). The average grain yield per plant under WW condition was 14.26 ± 0.22 and 16.16 ± 0.21 during 2019 and 2020, respectively. The mean grain yield under DS condition greatly reduced to 8.93 ± 0.17 and 10.31 ± 0.19 gm per plant during 2019 and 2020, respectively (Table 3). The grain yield reduction under DS compared to WW conditions in both the seasons indicated that drought stress at initial reproductive stage affected performance of the genotypes. At reproductive stage, drought stress alters the physiological mechanism which ultimately affects the yield and related traits of finger millet (Krishna *et al.,* 2021). Earlier findings reported that the drought stress reduces the grain yield in finger millet up to 18 to 25 per cent (Anonymous, 2008 and Reddy *et al*., 2020). The grain yield reduction also depends on the severity, duration and the stage of the crop. In the present study grain yield per plant under WW condition varied from 4.38 to 25.96 and from 5.98 to 30.00 in 2019 and 2020, respectively. Whereas, under DS the

TABLE 2

Mean sum of squares in 350 genotypes of finger millet for grain yield per plant under drought stress and well watered conditions

Source of variation	2019			2020		
	df	WW	DS	df	WW	DS
Blocks	4	2.17	14.5	6	1.36	3.94
Entries (Genotypes + Checks)	355	17.33	10.74	354	18.68 **	14.93 *
Checks	5	12.75	15.48	4	72.26 *	38.24 **
Genotypes	349	17.22 *	10.39 *	349	16.78 **	12.59 *
Checks vs. Genotypes	1	78.10 *	109.08 **	1	465.78 **	738.71 **
Error	20	16.12	5.91	24	6.43	8.06

* P <= 0.05; ** P <= 0.01; WW: well watered; DS: drought stress

grain yield per plant ranged from 1.66 to17.86 and from 2.64 to 22.26 during 2019 and 2020, respectively (Table 3). Overall, the genotypes recorded significant variability for grain yield under stress environment suggesting genotypic tolerance to drought stress. Some genotypes produced moderate to high grain yield under stress environment. However it is difficult to conclude the tolerance of a genotype by *per se* performance under stress environment (Edmeades, 2013). Plants cope with drought stress by a mixture of strategies that vary with genotypes and growth stage of the crop. In this regard, several criteria have been proposed to select genotypes based on their behavior in an environment under drought stress or without stress conditions (Naghavi *et al.*, 2013).

Stable yield performance of genotypes under both favorable and drought stress conditions is vital for plant breeders to identify drought tolerant genotypes. The high-yielding genotypes under optimum conditions may not be drought tolerant (Mardeh *et al.*, 2006); therefore, many studies preferred the selection based on drought tolerant indices that provides a measure of drought based loss in yield in comparison to well watered condition for screening the genotypes (Ali and El-Sadek, 2016). Different drought tolerance methods have been developed by scientist as selection criteria. The use of drought tolerance indices such as geometric mean productivity (GMP), mean productivity (MP), harmonic mean (HM), drought resistance index (DRI), yield index (YI), yield stability index (YSI) has been widely studied to identify drought tolerant genotypes in different crops (Naghavi *et al.*, 2013; Jalilvandy & Rozrokh, 2013; Menezes *et al.*, 2014 and Darkwa *et al.*, 2016). In the present study, grain yield under stress and well watered conditions were primarily used to determine the drought tolerance indices of the genotypes screened. The drought tolerance indices *viz.* GMP, MP, HM, DRI, YI and YSI were calculated for each genotype for both the years separately. High variability was observed among genotypes for all the drought tolerance indices studied (Table 4). The 350 genotypes were classified into five groups *viz.* tolerant, moderately tolerant, moderately susceptible, susceptible and highly susceptible based on their DTI values (Table 5). In both the years, majority of the genotypes were grouped under moderately susceptible followed by susceptible group

TABLE 3

Mean grain yield per plant under drought stress and well watered conditions during 2019 and 2020

Year	Treatment	Mean ± SE	Range (min-max)
2019	WW	14.26 ± 0.22	4.38 - 25.96
	DS	8.93 ± 0.17	1.66 - 17.86
2020	WW	16.16 ± 0.21	5.98 - 30.00
	DS	10.31 ± 0.19	2.64 - 22.26

WW: well watered; DS: drought stress

TABLE 4

Mean and range of different drought tolerance indices over the two years

DTI	Year	Mean ± SE	Range (min-max)
GMP	2019	10.79 ± 0.18	3.47 - 19.65
	2020	11.49 ± 0.19	3.16 - 22.54
MP	2019	11.32 ± 0.17	4.11 - 20.09
	2020	11.99 ± 0.18	4.01 - 22.84
HM	2019	10.31 ± 0.18	2.80 - 19.56
	2020	11.05 ± 0.19	2.27 - 22.48
DRI	2019	0.37 ± 0.01	0.01 - 1.03
	2020	0.38 ± 0.01	0.01 - 1.24
YI	2019	1.00 ± 0.02	0.19 - 2.12
	2020	0.99 ± 0.02	0.14 - 0.32
YSI	2019	0.60 ± 0.01	0.11 - 0.98
	2020	0.59 ± 0.01	0.14 - 0.98

and a very few genotypes recorded high susceptibility (Table 5). During 2019, in GMP 12 genotypes, MP 11 genotypes, HM 13 genotypes, DRI 15 genotypes, YI 13 genotypes and YSI only one genotype and in 2020, 13 genotypes in GMP, 11 genotypes in MP, 12 genotypes in HM, 17 genotypes in DRI, 15 genotypes in YI and 05 genotypes in YSI were found in drought tolerant group. In both the years, the number of genotypes in tolerant group was least for YSI compared to other DTI (Table 6). However some studies pointed out that the genotypes showing low fluctuation of yield under various levels of drought stress can be considered as drought tolerant along with drought tolerance indices for the stability of tolerance in the genotype (Ali and El-Sadek, 2016). Thus, by combining the performance of genotypes in both the years and across all the DTI, three genotypes *viz.* GE-1234, GE-1286 and GE-3003 were considered as drought tolerant genotypes. Among the three tolerant genotypes, the genotype GE-3003 found consistently in tolerant group for all the DTI and in both the years. Similarly, GE-1234 was also found in tolerant group for all the DTI in both the year except for YSI in 2019. Whereas, across all the DTI in both the years GE-1641, GE-3722 and GE-4719 genotypes were considered as highly drought susceptible genotypes. Out of the three susceptible genotypes, the genotype GE-1641 found consistently in susceptible group for all the DTI except for MP in 2020. Similarly, GE-4719 was also found in susceptible group for all the DTI except MP in 2019 (Table 7). The highest grain yield reduction under stress environment among tolerant genotype was observed in GE-1286 (26.42%) during 2020 followed by GE-1234 (25.25%) in 2019. The least reduction in grain yield among tolerant genotypes under stress was observed in GE-1286 (17.46%) during 2019 followed by GE-3003 (3.86%) in 2020 (Table 7). These genotypes recorded high values for drought tolerance indices *viz.* GMP, MP, HM, DRI, YI and YSI in both the years. The lowest grain yield per plant under

TABLE 5

Number of genotypes into different drought tolerance categories based on drought tolerance indices over the two years

Category	Year	GMP	MP	HM	DRI	YI	YSI
Tolerant	2019	12	11	13	15	13	01
	2020	13	11	12	17	15	05
Moderately tolerant	2019	35	45	42	38	36	58
	2020	41	43	40	33	38	48
Moderately susceptible	2019	241	236	230	231	235	233
	2020	239	242	241	252	238	239
Susceptible	2019	57	54	60	54	60	50
	2020	53	48	52	38	57	46
Highly susceptible	2019	05	04	05	12	04	08
	2020	04	06	05	10	02	12

TABLE 6

Drought tolerant and highly susceptible genotypes based on drought tolerance indices over the two years

Year	DTI	Tolerant genotypes	Highly susceptible genotypes
2019	GMP	GE-1286, GE-1260, GE-3758, GE-5118, GE-156, GE-2644, GE-1077, GE-1026, GE-290, GE-3003, GE-1234, GE-1013	GE-2272, VL-146, GE-4719, GE-2215, GE-1641
	MP	GE-1260, GE-1286, GE-3758, GE-5118, GE-290, GE-156, GE2644, GE-1026, GE-1077, GE-1234, GE-3003	GE-1080, GE-1641, GE-2215, GE-2272
	HM	GE-1286, GE-1260, GE-3758, GE-5118, GE-260, GE-156, GE-2644, GE-1077, GE-3003, GE1-026, GE-1234, GE -5004, GE-290, GE-1013	VL-146, GE-4839, GE-1743, GE-1641, KJNS-52
	DRI	GE-1286, GE-5004, GE-3090, GE-1381, GE-4995, GE-4013, GE-3003, GE-3758, GE-2664, GE-6595, GE-1077, GE-1531, GE-1234, GE-3638, GE-5118	GE-1417, GE-4601, GE-6336, GE-3101, GE-4951, GE-3722, VL-146, GE-1641, GE-4719, GE-1684, GE-4839, KJNS-52
	YI	GE-1286, GE-3758, GE-5004, GE-69, GE-3003, GE-1077, GE-5118, GE-1381, GE-1260, GE-2644, GE-1026, GE-2664, GE-1234	GE-4839, GE-4719, GE-1641, KJNS-52
	YSI	GE-3764	GE-4719, GE-4601, GE-4839, GE-4690, GE-1684, GE-4951, GE-3722, KJNS-52
2020	GMP	GE-489, GE-106, GE-1424, GE-832, GE-127, GE-3003, GPU-28, GE-3454, GE-909, GE-2056, KOPN-330, GE-1286, GE-1234	GE-1641, VL-146, GE-997, GE-4719
	MP	GE-106, GE-489, GE-1424, GE-832, GE-127, GPU-28, GE-909, GE-3003, KOPN-330, GE-3454, GE-2056	GE-4172, GE-1080, GE-70, GE-2215, GE-4719, GE-997
	HM	GE-489, GE-106, GE-1424, GE-832, GE-127, GE-3003, GE-3454, GE-2056, GPU-28, GE-909, GE-1234, GE-1286	GE-6336, GE-4601, GE-1641, GE-4719, VL-146
	DRI	GE-3003, GE-489, GE-469, GE-832, GE-1102, GE-3454, GE-127, GE-1234, GE-1260, GE-1298, GE-2056, GE-4149, GE-1309, GE-1424, GE-1640, GE-2275, GE-1381	GE-597, GE-1933, GE-6336, GE-2398, GE-4951, GE-3722, GE-1641, GE-4601, GE-4719, VL-146
	YI	GE-489, GE-3003, GE-832, GE-127, GE-1424, GE-3454, GE-469, GE-2056, GE-1234, GE-1260, GE-106, GE-4149, GE-1298, GE-1309, GE-1286	VL-146, GE-4719
	YSI	GE-469, GE-1102, GE-3003, GE-4995, GE-1234	GE-1026, GE-6336, GE-2770, GE-1641, GE-1399, GE-4951, GE-597, GE-2398, GE-4719, GE-3722, VL-146, GE-4601

drought stress was recorded in genotype GE-1641 (1.76g) and in GE-4719 (1.34g) during summer 2019 and 2020, respectively. The highest reduction in grain yield per plant over the two years was recorded in GE-3722 (83.68% and 83.50%) followed by GE-4719 (77.11% and 82.08%). The results indicate that all the three tolerant genotypes consistently showed less than 26 per cent yield reduction under stress environment while the three susceptible genotypes recorded more than 74 per cent yield reduction in both the years. Mousavi *et al.,* (2008) reported the yield stability is more important than high yield for these indices.

Table 7

Stable drought tolerant and highly susceptible genotypes selected based on the drought tolerance indices over the two years

Genotypes	DTIs (summer 2019)						DTIs (summer 2020)						GYP (summer 2019)		GYP (summer 2020)	
	GMP	MP	HM	DRI	YI	YSI	GMP	MP	HM	DRI	YI	YSI	Yp	Ys	Yp	Ys
DT GE-1234	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	19.96	14.92 (25.25)	20.22	17.28 (14.54)
GE-1286	✓	✓	✓	✓	✓		✓		✓				21.64	17.86 (17.46)	21.80	16.04 (26.42)
GE-3003	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	19.96	16.08 (19.43)	20.18	19.40 (3.86)
DS GE-1641	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	6.86	1.76 (74.34)	8.30	1.98 (76.14)
GE-3722				✓		✓				✓		✓	18.76	3.06 (83.68)	17.46	2.88 (83.50)
GE-4719	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	8.04	1.84 (77.11)	7.48	1.34 (82.08)
Mean gain yield per plant													14.26	8.39	14.99	8.99

DT: Drought tolerant, DS: Drought susceptible, ✓: indicates the genotype selected across the DTI, GYP: Grain yield per plant (g), Values in parenthesis indicates the *per cent* reduction in grain yield per plant under the drought stress compared to the well watered condition

Ghasemi and Farshandfar (2015) in wheat, Yousefi (2015) in barely, and Mohammadi (2016) in durum wheat confirmed that high values of STI, MP, GMP, YSI, and YI are the best indices for identification of superior genotypes under drought and non-stress conditions. Naghavi *et al*., (2013) in maize reported that GMP, MP, YI, YSI, and DRI were positively correlated with seed yield under drought stress conditions. Similarly the mean grain yield under drought stress was significantly correlated with GMP, MP, YI, YSI, DRI, and HM in tef (Ferede *et al*., 2020). In view of consistent performance of the genotypes for different DTI over the two years, the genotype GE-1234, GE-3003 and GE-1286 were considered as stable drought tolerant genotypes and the genotypes GE-1641, GE-4719 and GE-3722 were considered as drought susceptible genotypes.

The present study indicated significant variability among the genotypes for seed yield under stress and well watered conditions. The yield reduction under stress was also not uniform across genotypes over the two years suggesting genotypes respond differentially for reproductive stage drought stress in finger millet. Similarly, there was a variation in the response of genotypes for drought stress across two years. However, by using a combination of drought tolerance indices which mainly depended on the effect of drought stress on grain yield three stable drought tolerant genotypes *viz.* GE-1234, GE-1286 and GE-3003 were identified. The highly susceptible genotypes *viz.* GE-1641, GE-3722 and GE-4719 were found. The selected drought tolerant genotypes with least reduction in grain yield under stress a vice versa in case of susceptible genotypes with highest reduction in grain yield confirming the usefulness of drought tolerance indices in the identification of stable contrasting genotypes for drought tolerance.

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