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Effect of Moderate Drought Stress on Photosynthetic Rate and Grain Yield in Finger Millet Genotypes

Y.A. Nanja Reddy[1,2*], Jayarame Gowda[2], E.G. Ashok[2] and K.T. Krishne Gowda[2]

[1]Department of Crop Physiology, [2]AICRP on Small Millets, University of Agricultural Sciences, GKVK, Bangalore 560065, Karnataka, India

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A B S T R A C T

In the changing climate scenario, drought could be continued as a major abiotic limitation for crop productivity. Finger millet although known for its drought tolerance, the drought stress decreases the grain yield from 25 to 100 percent depending on the duration and magnitude of drought stress. Present study was conducted to explore the genetic variability of selected genotypes over the ruling varieties if any, based on the extent of reduction in grain yield, and dependent photosynthetic traits due to moderate drought stress for 18 to 20 days (grand growth to flower primordial initiation). Five selected genotypes were compared with three released varieties under field condition by withholding the irrigation for stress treatment. Moderate drought stress for a period of 18 to 20 days decreased the photosynthetic rates markedly due to decreased stomatal conductance and transpiration rates. However, yield reduction was less than 6.0 per cent in released varieties. Correlations and path analysis proved that, the mean ear weight and productive tillers per hill are important in yield determination of finger millet under drought condition. Among the varieties, Cv. PR-202 found relatively drought tolerant and this variety can be used as check for screening germplasm accessions against the drought stress. It is concluded that, moderate drought stress for 18 to 20 days with pan evaporation of around 4 mm per day is not a serious limitation under rainfed situations during *kharif* seasons.

Introduction

Finger millet belongs to family Poaceae (Dida *et al.*, 2007) with C_4 pathway (Ueno *et al.*, 2006; Sage and Zhu, 2011) suitable to rainfed situations. Finger millet is grown in arid and semi-arid regions in more than 25 countries, predominantly in India and Africa. The grain is nutritionally rich in calcium, iron, zinc, magnesium, potassium, and others with low glycemic index and presence of anti-nutritional factors like phytic acid and tannins (Chethan and Malleshi, 2007; Devi *et al.*, 2014; Gupta *et al.*, 2017; Sharma *et al.*, 2017; Netravathi *et al.*, 2018; Nanja Reddy *et al.*, 2019b). Owing to its nutritional quality and to meet the regional food and fodder security, it is cultivated as rainfed crop in 90 % of finger millet area (Davis *et al.*, 2019). In India, it is cultivated in an area of 1.19 m ha with production of 2.0 m t with a major contribution (58 %) from the state of

Karnataka (Malhotra, 2018, Sakamma *et al*., 2018). Under rainfed conditions drought stress (DS) for 15 to 30 days is a common feature and will continue as a major abiotic limitation for productivity in the changing climate scenario.

Drought stress (DS) affect the crop yield for instance, a 10 % drop in rainfall results in 4.2 % decrease in grain yield of cereal crops (Webb and Braun, 1994). Simulation models predict that DS reduces the grain yield of wheat and maize to the extent of 21 to 40 % on global scale (Daryanto *et al*., 2014). Drought stress for 25 to 30 days invariably occurs during one or the other crop growth stages during monsoon season and decreases the grain yield finger millet up to 25 % (Anon, 2008). While prolonged DS from 28 DAS to till the crop maturity decreased the grain yield by 109.8 % (Maqsood and Azam Ali, 2007).

Recently, it is predicted that Indian monsoon precipitation would increase in future years due to increasing vaporization accountable to increase in CO_2, aerosols and deforestation (Jalihal *et al*., 2019). However, the frequency of DS is increasing with irregular distribution of rainfall and a fewer rainy days during monsoon season (Dash *et al*., 2009). The rainfall pattern from 2010 to 2019 at the experimental station show that, during cropping season (July to October), the rainfall was 526.4 $\pm$ 153.3 mm with 32.5 $\pm$13.9 rainy days, suggesting a highly unpredictable variations in rainfall distribution during monsoon season (Anon, 2019). For these situations, relatively finger millet is the most suitable crop as it is highly climate resilient compared to other major cereal crops. However, owing to reduction in grain yield due to DS, studies on elite genotypes in comparison with popular varieties could be useful to explore the genetic variability. In any genotype, the grain yield under DS is the product of biomass and harvest index, but the yield attributing characters are determined by the photosynthetic capacity of a genotype. Therefore, a study was conducted to quantify the effect of moderate drought stress (grand growth stage to flower primordial initiation) on gas exchange traits and yield attributing characters in selected finger millet genotypes.

Materials and Methods

Experiment was conducted at the field Unit, AICRP (Small Millets), Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bengaluru-65 during *kharif*, 2008. The location is situated at 12º58¹ North latitude and 77º35¹ East longitude at an altitude of 930 meter above the MSL and has red sandy loam soil. Eight selected genotypes (given with results) were sown directly in the field on 28th July 2008 and thinned to single plant per hill within 20 days after sowing (DAS). The experiment was planned in split plot design with eight genotypes in three replications. Each replication had 13 rows of 3.0 m length in the spacing of 30 cm between rows and 10 cm between plants. The gross plot size was 3.9 m x 3.0 m (11.7m^2). During the crop growth period, rainfall did not occur from 10th Sept to 4th October, 2008 (25 days), during this 25 day period, two irrigations of 10 mm each were provided to rainfed treatment called as control and; the other treatment drought stress (DS) was continued to be under stress condition for 25 days. These two plots were separated by 3.0 m apart to avoid the irrigation drift. The crop growth phase during stress period was coincided from grand growth to initiation of ear emergence. The fertilizer dose was 50:40:25 kg ha^{-1} (N: P: K respectively) was applied. The entire dose of P and K; and half dose of nitrogen were applied at the time of sowing. The remaining N was supplied 40 days after sowing. Two hand weedings were taken before 30 DAS.

The details of rainfall and the stress treatment are as follows; on 9th September 2008, 26.4 mm rainfall was occurred. It could take nearly 6 days for exhausting (to initiate drought stress) the preceding rainfall of 26.4 mm with existed average pan evaporation was 4.2 mm per day. The total pan evaporation during the stress period was 113.9 mm, with rainfall of 26.4; hence the net deficit of rainfall was 107.5 mm in 18 days @ 4.2 mm d^{-1}. This stress period for 18 to 20 days is called moderate drought stress.

At the end of stress period, gas exchange parameters were measured using Infrared Gas Analyzer (IRGA) (LI 6400) from 10.00 to 11.00 AM on fully expanded 3rd leaf from the apex. The measurements were made from 21st (15 days of actual stress) to 23nd day (17 days of actual stress) after stress imposition. The yield attributes *viz*., productive tillers, mean ear weight, finger length and number of fingers per ear was measured at the time of harvest. The grain yield was recorded in net plot area of 11 rows leaving the border rows and two hills on each side of the row (2.6 m x 2.7 m). The productive tiller number and other parameters were recorded in 1.0 meter row length of 10 plants. The data was statistically analyzed in split plot design for genotypic performance. Pearson correlations between traits and the path analysis was followed to identify the contribution of each trait towards grain yield using OPSTAT package developed CCSHAU, Hisar (Sheoran *et al*., 1998).

Results and Discussion

C_4 photosynthesis is most efficient due to CO_2 concentrating mechanism in bundle sheath cells and high RuBisCo activity with a reduction in photorespiration (Sage and Zhu, 2011). However, the moderate drought stress (DS) for 18 days during grand growth stage to panicle primordial initiation, significantly decreased the mean photosynthetic rate by 16.6 per cent (Table 1; Mohanabharathi *et al*., 2019). Significant genotypic variations for photosynthetic rate were observed both under control and stress condition. Under stress condition, Cv. PR-202 recorded highest photosynthetic rate (31.5 u Mol. $m^{-2}s^{-1}$) with a least per cent reduction of only 4.0 per cent. Similar genotypic variations in photosynthetic rates under stress conditions were reported (Subramanyam, 2000; Gupta *et al*., 2011).

Higher photosynthetic rate in PR-202 under moderate drought stress was due to higher stomatal conductance and transpiration rates. This suggests that per unit of water transpired the CO_2 uptake was high, thus resulted in higher carboxylation and photosynthetic rate. Higher stomatal conductance in Cv. PR-202 infers that, it has better water relations as character *per se*. The photosynthetic rate was positively and markedly related to stomatal conductance and transpiration rate under control condition (Table 2: Anitha *et al*., 2019; Mohanabharathi *et al*., 2019; Maai *et al*., 2020). However, the relationship was highly significant under stress condition (r= 0.804* and 0.811** respectively). This suggests that, stomatal responses are important under drought stress condition.

Moderate DS decreased the mean grain yield by 9.5 % (Table 3; Suma, 2014; Mohanabharathi *et al*., 2019). The grain yield due to stress was less affected in Cv. PR-202 (5.6 %), MR-6 (5.3 %) and HR-911 (6.4 %). But the absolute grain yield under stress was higher in MR-6 (35.8), GE-1034 (35.8), GE-1013 (36.0 q ha^{-1}), and HR-911 (37.2) as compared to PR-202. However, only HR-911 was significantly superior over the Cv. PR-202. The productive tillers per hill influence the grain yield of finger millet positively (Nanja Reddy *et al*., 2019a).

Table.1 Influence of moderate drought stress on photosynthetic characters in selected finger millet genotypes

Variety	Photosynthetic rate (u mol m^{-2} s^{-1})				Conductance (mol m^{-2} s^{-1})				Transpiration rate (m mol m^{-2} s^{-1})			
	C	DS	Mean	% Red.	C	DS	Mean	% Red.	C	DS	Mean	% Red.
GE - 1013	27.8	25.9	26.9	6.8	0.22	0.19	0.21	13.6	4.06	2.88	3.47	29.1
GE - 3069	35.6	26.6	31.1	25.3	0.22	0.20	0.21	9.1	4.43	3.34	3.89	24.6
PR - 202	32.1	30.8	31.5	4.0	0.30	0.31	0.31	-3.3	4.55	3.43	3.99	24.6
GE - 3457	26.7	23.2	25.0	13.1	0.16	0.15	0.16	6.3	3.31	2.71	3.01	18.1
GE - 4777	29.4	24.5	27.0	16.7	0.19	0.15	0.17	21.1	3.30	2.73	3.02	17.3
HR - 911	32.7	28.2	30.5	13.8	0.27	0.15	0.21	44.4	3.70	3.06	3.38	17.3
MR - 6	31.2	22.2	26.7	28.8	0.23	0.14	0.19	39.1	3.50	2.47	2.99	29.4
GE - 1034	32.4	24.6	28.5	24.1	0.23	0.16	0.20	30.4	3.74	2.26	3.00	39.6
Mean	**31.0**	**25.8**	**28.4**	**16.6**	**0.23**	**0.18**	**0.21**	**20.1**	**3.83**	**2.86**	**3.35**	**25.0**
	SEm	CD			SEm	CD			SEm	CD		
Treatment	0.21	0.61			0.003	0.01			0.05	0.14		
Variety	0.42	1.21			0.005	0.01			0.09	0.26		
V x T	0.60	1.73			0.007	0.02			0.13	0.38		
CV (%)	4.7				6.2				6.8			

C: Control, DS: Moderate drought stress, % Red.: Per cent reduction under stress, SEm± and CD @ 5%.

Table.2 Pearson Correlation between photosynthetic parameters in finger millet genotypes under control and moderate drought stress conditions

Character	Control			Drought Stress		
	A	g_s	T	A	g_s	T
Photosynthetic rate (A)	1.000			1.000		
Stomatal conductance (g_s)	0.565	1.000		0.804	1.000	
Transpiration rate (T)	0.564	0.647	1.000	0.811	0.716	1.000

Table.3 Influence of moderate stress on seed yield and yield related parameters in selected finger millet genotypes

Variety	Seed yield (q.ha^{-1})				Mean ear wt. (g)				Prod. tillers/ mrl				Ear length (cm)				Fingers/ Earhead			
	C	DS	Mean	% Red.	C	DS	Mean	% Rd.	C	DS	Mean	% Rd.	C	DS	Mean	% Rd.	C	DS	Mean	% Rd.
GE - 1013	40.0	36.0	38.0	10.0	6.33	6.25	6.29	1.3	29.3	31.3	30.3	-6.8	7.62	7.65	7.64	-0.4	7.53	8.07	7.80	-7.2
GE - 3069	20.0	17.4	18.7	13.0	5.46	4.91	5.19	10.1	37.3	27.3	32.3	26.8	8.00	7.47	7.74	6.6	8.01	6.13	7.07	23.5
PR - 202	36.0	34.0	35.0	5.6	4.51	4.37	4.44	3.1	48.3	46.7	47.5	3.3	5.13	4.87	5.00	5.1	6.43	6.90	6.67	-7.3
GE - 3457	32.1	27.7	29.9	13.7	4.66	4.44	4.55	4.7	32.0	31.0	31.5	3.1	5.47	5.09	5.28	7.0	7.10	6.63	6.87	6.6
GE - 4777	31.5	25.9	28.7	17.8	6.26	5.57	5.92	11.0	27.0	24.3	25.7	10.0	5.79	5.28	5.54	8.8	8.27	7.60	7.94	8.1
HR - 911	39.6	37.2	38.4	6.4	6.49	7.20	6.85	-10.9	31.7	31.7	31.7	0.0	8.05	7.90	7.98	1.9	7.83	7.57	7.70	3.3
MR - 6	37.8	35.8	36.8	5.3	5.28	5.54	5.41	-4.9	32.3	31.7	32.0	1.9	8.42	7.55	7.99	10.3	7.00	6.33	6.67	9.6
GE - 1034	39.5	35.8	37.7	9.4	5.74	6.27	6.01	-9.2	37.3	34.3	35.8	8.0	8.51	8.49	8.50	0.2	8.17	7.40	7.79	9.4
Mean	**34.6**	**31.3**	**33.0**	**9.5**	**5.59**	**5.57**	**5.58**	**0.4**	**34.4**	**32.2**	**33.3**	**6.4**	**7.13**	**6.79**	**6.96**	**4.8**	**7.54**	**7.08**	**7.31**	**6.1**
	SEm	CD			SEm	CD			SEm	CD			SEm	CD			SEm	CD		
Treatment	0.50	1.30			NS	NS			0.53	1.53			0.022	0.06			0.03	0.09		
Variety	1.00	2.60			0.14	0.40			1.05	3.03			0.046	0.13			0.06	0.17		
V x T	NS	NS			0.19	0.55			NS	NS			0.065	0.19			0.08	0.23		
CV (%)	6.7				8.9				11.6				3.6				2.9			

C: Control, DS: Moderate drought stress, % Red.: Per cent reduction under stress, mrl: meter row length of 10 plants, NS: Non-significant, SEm± and CD @ 5%.

Table.4 Pearson correlation between yield and yield attributes in finger millet genotypes under control and moderate drought stress conditions

Character	Control					Drought Stress				
	Grain yield	Mean ear wt.	Prod. tillers/ mrl	Finger length	Finger No./ ear	Grain yield	Mean ear wt.	Prod. tillers/ mrl	Finger length	Finger No./ ear
Grain yield	1.000					1.000				
Mean ear weight	0.249	1.000				0.539	1.000			
Prod. tillers/ mrl	-0.088	-0.664	1.000			0.480	-0.281	1.000		
Finger length	0.164	0.495	-0.230	1.000		0.301	0.734	-0.229	1.000	
Finger No./ ear	-0.222	0.745	-0.536	0.439	1.000	0.512	0.651	-0.051	0.150	1.000

Table.5 Path coefficient analysis of yield attributes towards grain yield in finger millet genotypes under control and moderate drought stress conditions

Character	Control					Stress				
	Mean ear wt.	Prod. tillers/ mrl	Finger length	Finger No./ ear	R	Mean ear wt.	Prod. tillers/ mrl	Finger length	Finger No./ ear	r
Mean ear weight	**0.908**	-0.030	0.066	-0.695	0.249	**0.802**	-0.190	-0.103	0.030	0.539
Prod. tillers/ mrl	-0.602	**0.045**	-0.031	0.500	-0.088	-0.226	**0.676**	0.032	-0.002	0.480
Finger length	0.450	-0.010	**0.133**	-0.409	0.164	0.589	-0.155	**-0.141**	0.007	0.301
Finger No./ ear	0.677	-0.024	0.059	**-0.933**	-0.222	0.522	-0.034	-0.021	**0.046**	0.512

mrl: meter row length of 10 plants, r: correlation coefficient

In the present study, the mean productive tillers per hill were reduced by 6.4 % due to moderate DS (Table 3; Ludlow and Muchow, 1990) probably stress during panicle formation could decrease the conversion of vegetative tiller to productive tiller. Mean ear weight influences the grain yield to a greater extent under a given condition (Nanja Reddy *et al*., 2019a). In fact the early selection in finger millet was in the direction of ear size, and the ear size will be affected by severe stress (Suma, 2014). In the present study no reduction was observed as the exposure to stress was completed by the time of flowering and subsequent ear development and; mainly it was a mild stress. However, it has been suggested that large ear size with thicker leaves could be more appropriate for rainfed conditions (Sastry *et al*., 1982). The moderate moisture stress did not affect much the finger length (4.8 %) and finger number/ ear (6.1 %) because the stress was relieved by the time of flowering and; the early effect was mild.

Several reports show that, the grain yield was positively related to ear size and productive tillers per unit area (Prakasha *et al*., 2018; Nanja Reddy *et al*., 2019a). In addition, the finger number and length are also important for higher grain yield (Rani *et al*., 20015; Negi *et al*., 2017; Mahanthesha *et al*., 2018; Sneha *et al*., 2019). In the present study, the relationship between grain yield with mean ear weight, productive tillers, finger length and finger number was strong under DS condition as compared to control condition (Table 4). Such contribution under stress condition was confirmed by path analysis. Results of path analysis show that only mean ear weight is important and productive tillers is not a constraint for productivity under control condition; while under DS condition, both mean ear weight and productive tillers are important in determining the grain yield (Table 5).

These results suggests that, moderate drought stress during grand growth stage to flower primordial initiation, affect the gas exchange parameters to a higher extent as compared to the yield and yield attributing traits.

The released varieties are not affected by a moderate DS for 18-20 days with pan evaporation of 4.2 mm/ day in red sandy loam soils. Furthermore, finger millet being a C_4 species moderate stress could lead to only a marginal decrease in grain yield. Under DS condition both productive tiller number and ear size are important in grain yield formation, but in control productive tillers was not a constraint for productivity. The better performance of PR-202 in trait *per se*in the present study and in earlier studies, suggests that it can be termed as relatively drought resistant and can be used as check in genotypic screening for drought resistance.

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