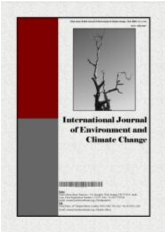

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Morpho-physiological Responses of Sorghum Cultivars to Drought Stress

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The experiment was carried out to assess the following objectives: (i) To understand the effect of drought stress on plant height and leaf area in diverse sorghum genotypes. (ii) To study the alterations in chlorophyll index and yield components under drought stress. (iii) To correlate yield with all morpho-physiological traits to understand drought tolerance mechanism of sorghum. Screening experiment was carried out in Augmented design I during April 2022 to July 2022 at Rain Out Shelter (ROS), Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore. 33 germplasms from Agricultural Research Station, Kovilpatti (ARS, Kovilpatti) and Indian Council of Agricultural Research- Indian Institute of Millet Research, Hyderabad (ICAR-IIMR, Hyderabad) were collected. Among 33, M35-1, K -12, CSV 27 and CSV 29-R were used as checks, where all the germplasms were cultivated with two treatments under field conditions; T_1: (Control) well watered throughout life cycle, T_2: Two weeks of drought stress (50%) at booting stage. Traits such as plant height and leaf area, were recorded before and after imposing drought. Chlorophyll index, ear head weight, ear head length, grain yield, total dry matter production, harvest index were recorded after imposing drought stress in control and drought stress. Under drought stress morpho-physiological and yield traits significantly reduced compared to control. There was a significant positive correlation of yield under stress with all the morpho-physiological traits. Among ICAR-IIMR sorghum germplasm collections screened for drought stress tolerance

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PEC 14, PEC 17, PEC31, PEC 34 EP 90 showed drought tolerance on par with the checks. Similarly, TKSV 1036, TKSV 1707, TKSV 1801, TKSV 1802 germplasms from ARS, Kovilpatti were tolerant to drought stress at booting stage.

Keywords: Drought; yield traits; harvest index; chlorophyll index; total dry matter production.

1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is also known as grain sorghum, is an essential food crop. Sorghum can be grown in harsh environment with little inputs and cropping practises used in arid and semi-arid regions of the world making it more productive [1]. In India, sorghum is mainly cultivated by marginal farmers in rainy (rabi) season.

Indian sorghum has higher cultivation area, production and productivity of 40.93 lakh/ha, 34.75 lakh tonnes and 849 kg/ha respectively [2]. In Tamil Nadu the crop is cultivated in an area of 3.86 lakh/ha with maximum production (4.64 lakh tones) and productivity (535 kg/hectare) [2].

Intergovernmental Panel on Climate Change IPCC (2021) has predicted that rainfall patterns in sorghum growing areas will be highly variable. In addition Climate change prediction showed that there would be abrupt change in rainfall patterns in the next four decades combined with the risk of high temperature, which will intensify the drought stress [3]. Sorghum has wide range of adaptability and can be grown in various series of environment including heat, drought, salinity and flooding [4]. Drought during anthesis and grain filling is believed to be the most susceptible growth stages, resulting in the highest yield reduction [5].

Water stress limits grain yield during the reproductive and in post-anthesis periods approximately55% [6] and 43% [7] respectively. The severity of drought stress in plants can be measured at morphological levels [8]. When the plants are exposed to drought stress following parameters *viz.,* plant height, tiller numbers, leaf size and leaf area are affected [9]. Drought stress can reduce the expression of chlorophyll contents [10]. This could be related to the generation of reactive oxygen species, which causes lipid peroxidation and, as a result, damages the structure of chlorophyll [11].

Drought stress reduces the ear head length, ear head weight, seed yield at eight-leaf stage in sorghum [12]. Grain yield is affected by both, duration and severity of the drought stress and dry matter production in sorghum decreased under drought condition [13].

India has a wealth of germplasm accession, mini core collection and breeding lines developed for drought tolerance, which are not validated. Hence, the study aimed to collect the available germplasm collections from ICAR-IIMR, Hyderabad and ARS, Kovilpatti to understand the drought tolerance of sorghum by morpho-physiological traits. The experiment was conducted to evaluate with the objectives; (i) to understand the effect of drought stress on plant height and leaf area in diverse sorghum genotypes. (ii) to study the alterations in chlorophyll index and yield components under drought stress (iii) to correlate yield with all morpho-physiological traits to understand drought tolerance mechanism of sorghum.

2. MATERIALS AND METHODS

2.1 Plant Material

Twenty nine sorghum genotypes with four checks differing in their tolerance behavior to drought stress were taken for the study during the period of April 2022 to July 2022. Sorghum germplasm *viz.,* TKSV 1036, TKSV 1146, TKSV1158, TKSV 1704, TKSV 1707, TKSV 1712, TKSV 1801, TKSV 1802, K8 and drought checks K12 were collected from ARS, Kovilpatti and the remaining checks *viz.,* M35-1, CSV 27 and CSV 29-R and other germplasms were collected from ICAR-IIMR, Hyderabad.

2.2 Drought Stress Imposition

The Sorghum plants were raised with a spacing of 45x15 cm at Rain Out Shelter (ROS), Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore. Drought stress treatments were imposed inside ROS meanwhile control area was maintained adjacent to the ROS facility. The dimensions of the ROS and the control area measured 21 m in length and 6m in width. Both control and stress area were ploughed, finally ridges and furrows were made. Recommended dosage of basal fertilizer was applied, 90:45:45 of N, P, and K kg/ha respectively. The treatment details are as follows:

T_1: (Control) well watered throughout lifecycle.

T_2: two weeks of drought stress starting at booting stage (50^{th} day).

Treatments for drought stress were measured by moisture content using an ML2 theta probe moisture meter (Delta-T Soil moisture kit – Model: SM 150, Delta-T Devices, Cambridge).

Moisture content of 5.7%, 5.6%, 4.6% were recorded at drought stressed plots measured in different places, whereas moisture content of 31.8%, 29.7%, 28.4% were recorded at control plots. On an average 6% moisture content was maintained in drought stresses plots for a period of two weeks.

2.3 Morpho-physiological Traits

2.3.1 Stage of observation

Plant height, leaf area, chlorophyll index was measured before imposing drought stress at booting stage and after imposing drought stress at half bloom stage.

2.3.2 Plant height

Five plants from each genotype were taken before imposing drought stress at booting stage and after imposing drought stress at half bloom stage to measure the average plant height. The plant's height was measured from the base (ground level) to the tip of the panicle and expressed in centimeters (cm).

2.3.3 Leaf area

Five sorghum leaves were collected in each genotype before imposing stress at booting stage and after imposing drought stress at half bloom stage. Leaf area was measured using Leaf area meter (LICOR, Model LI 3000) and expressed as cm^2/plant.

2.3.4 Chlorophyll index

Chlorophyll index was recorded before and after imposing drought stress during booting and half bloom stage respectively using a handheld chlorophyll meter (Minolta SPAD 502). It measures chlorophyll content as a ratio of light transmittance at 650 nm and 940 nm. Five readings were collected from each genotype, and the average was recorded using the Minolta method [14].

2.3.5 Yield and yield components

The ear heads of control and drought stressed plots were harvested at 120 (DAP) when they attain physiological maturity and kept for sun drying followed by oven dry at 72ºC for 48 hours. Then the ear head weight (g) and ear length (cm) were measured using weighing balance and centimeter scale respectively [15]. After the harvest of ear head at 120 (DAP), grains were collected from five (both control and drought stressed) plants and their weights were recorded using weighing balance. The average grain yield per plant is calculated. The total grain yield per plant was expressed as g/plant [16]. The plants were shade dried for 48 hours before being oven dried at 72ºC for biomass measurement. The dry weight of the entire plant at maturity (120 DAP) was measured and expressed in g/plant [16].

Harvest index: This was considered as ratio of economic yield to biological yield [17] and calculated as follows:

1. Harvest Index (HI) = Economic yield / Biological yield

2.4 Statistical Analysis

The experiment was carried out in Augmented design I where the number of checks were repeated uniformly throughout the experiment. Only Checks were replicated in this design. A Pearson correlation was done in the experiment using SPSS (Statistical Package for Social Sciences) software to correlate the physiological parameters with yield traits.

3. RESULTS

3.1 Morphophysiological Traits

3.1.1 Plant height (cm)

Plant height of all sorghum genotypes was measured at both, before and after imposing stress. Before imposing drought stress the plant height was highest (250 cm) in PEC 36 and lowest (140 cm) in CSV-27 (Table 2). Plant height of sorghum varied from 140 to 308 cm under the drought stress (Table 3). Among the 4 checks, M35-1was found taller (287.60 cm) under drought stress and among the 29 genotypes. PEC 17 had taller plants (280 cm) under drought stress followed by PEC 34, EP 90, PEC 14 whereas, the plants such as EN 55 was shorter (140.66 cm) followed by EP 72 (144.33 cm) and EP 87 (150.33 cm) under drought stress. Plant height exhibited highly significant and positive correlation with grain yield (Table 6).

Table 1. List of genotypes used in this experiment

Sl. No.	Genotypes/ Acc. No.	Sl. No.	Genotypes/ Acc. No.	Sl. No.	Genotypes/ Acc. No.
1.	TKSV 1036	12.	PEC 14	23.	PEC 36
2.	TKSV 1146	13.	PEC 16	24.	EN 55
3.	TKSV 1158	14.	PEC 17	25.	EP 72
4.	TKSV 1704	15.	PEC 22	26.	EP 87
5.	TKSV 1707	16.	PEC 23	27.	EP 90
6.	TKSV 1712	17.	PEC 24	28.	EP 93
7.	TKSV 1801	18.	PEC 31	29.	EP 94
8.	TKSV 1802	19.	PEC 32	30.	M 35-1(check 1)
9.	K8	20.	PEC 33	31.	K 12 (check 2)
10.	PEC 5	21.	PEC 34	32.	CSV-27 (check 3)
11.	PEC 12	22.	PEC 35	33.	CSV-29-R (check 4)

Table 2. Genetic variability in morphological traits of sorghum before imposing stress

Genotypes	Plant height (cm)	Leaf area (cm^2/plant)
TKSV 1036	173.33	300.56
TKSV 1146	170.57	350.66
TKSV 1158	200.00	309.21
TKSV 1704	159.40	310.30
TKSV 1707	160.00	490.68
TKSV 1712	195.15	130.24
TKSV 1801	188.41	186.90
TKSV 1802	183.63	233.42
K8	179.30	177.97
PEC 5	170.00	499.89
PEC 12	200.30	197.60
PEC 14	215.00	400.80
PEC 16	199.50	160.10
PEC 17	230.00	250.67
PEC 22	210.50	350.50
PEC 23	200.60	299.28
PEC 24	217.00	320.30
PEC 31	195.00	200.43
PEC 32	198.30	179.89
PEC 33	189.00	390.00
PEC 34	200.00	184.92
PEC 35	210.90	140.44
PEC 36	250.00	194.31
EN 55	230.00	169.25
EP 72	198.30	294.39
EP 87	197.00	200.10
EP 90	150.90	300.22
EP 93	186.00	266.56
EP 94	189.00	194.39
M 35-1(check 1)	160.40	350.57
K 12 (check 2)	180.00	240.45
CSV-27 (check 3)	140.00	369.38
CSV-29-R (check 4)	155.00	324.32

Genotypes	Plant height (cm)		Leaf area (cm^2/plant)	
	S.Ed	**(*P*<0.05)**	**S.Ed**	**(*P*<0.05)**
Test Entries	2.5	5.4	1.4	4.3
Checks	1.1	2.4	0.6	1.9
Test V check	1.9	4.1	1.1	3.3

S.Ed = Standard error of difference

Table 3. Variation in plant height of sorghum exposed to water deficit stress

Genotypes	Control		Drought Stress		Percentage Reduction
	Plant height (cm)		**Plant height (cm)**		**Plant height (%)**
TKSV 1036	245.00		230.00		6.12
TKSV 1146	250.60		185.22		26.09
TKSV 1158	245.00		175.87		28.22
TKSV 1704	186.66		180.00		3.57
TKSV 1707	239.60		221.66		7.49
TKSV 1712	235.60		209.66		11.01
TKSV 1801	235.30		220.00		6.50
TKSV 1802	227.00		210.00		7.49
K8	215.33		195.00		9.44
PEC 5	227.00		204.66		9.84
PEC 12	249.30		267.83		11.89
PEC 14	256.60		240.66		6.21
PEC 16	229.00		200.33		12.52
PEC 17	300.30		280.00		6.76
PEC 22	240.00		211.00		12.08
PEC 23	231.60		201.33		13.07
PEC 24	236.00		204.33		13.42
PEC 31	248.30		230.66		7.10
PEC 32	212.60		187.33		11.89
PEC 33	215.30		193.00		10.36
PEC 34	277.60		260.00		6.34
PEC 35	235.00		211.66		9.93
PEC 36	250.43		215.73		13.86
EN 55	241.60		140.66		41.78
EP 72	230.00		144.33		37.25
EP 87	200.00		150.33		24.84
EP 90	274.30		259.33		5.46
EP 93	240.48		208.30		13.38
EP 94	241.33		207.00		14.23
M 35-1(check 1)	313.66		287.60		8.31
K 12 (check 2)	280.60		266.00		5.20
CSV-27 (check 3)	269.00		250.00		7.06
CSV-29-R (check 4)	265.60		249.33		6.13
	S.Ed	**(*P* <0.05)**	**S.Ed**	**(*P* <0.05)**	
Test Entries	2.3	5.0	1.4	3.1	
Checks	1.0	2.2	0.6	1.4	
Test V check	1.8	3.9	1.1	2.4	

S.Ed = Standard error of difference

Table 4. Variation in leaf area of sorghum exposed to water deficit stress

Genotypes	Control		Drought Stress		Percentage Reduction
	Leaf area (cm^2/plant)		Leaf area (cm^2/plant)		Leaf area (%)
TKSV 1036	360.23		334.67		7.10
TKSV 1146	386.79		224.13		27.88
TKSV 1158	358.19		218.00		26.89
TKSV 1704	369.88		314.50		14.97
TKSV 1707	354.33		326.98		7.72
TKSV 1712	108.46		269.57		12.61
TKSV 1801	330.02		305.63		7.39
TKSV 1802	321.16		299.49		6.75
K8	258.31		230.97		10.58
PEC 5	289.11		259.72		10.17
PEC 12	300.33		230.41		13.97
PEC 14	379.45		350.08		7.74
PEC 16	288.30		254.46		11.74
PEC 17	410.80		383.99		6.53
PEC 22	299.46		265.52		11.33
PEC 23	292.70		262.60		10.28
PEC 24	276.56		235.27		14.93
PEC 31	370.77		344.20		7.17
PEC 32	285.96		254.62		10.96
PEC 33	299.17		267.38		10.63
PEC 34	396.00		365.90		7.60
PEC 35	248.10		220.23		11.23
PEC 36	305.93		263.28		13.94
EN 55	287.62		189.05		34.27
EP 72	318.50		198.60		37.65
EP 87	339.87		200.96		40.87
EP 90	394.09		363.05		7.88
EP 93	249.39		223.90		10.22
EP 94	250.09		214.75		14.13
M 35-1(check 1)	429.31		399.40		6.97
K 12 (check 2)	400.00		370.89		7.28
CSV-27 (check 3)	388.90		357.72		8.02
CSV-29-R (check 4)	386.08		355.13		8.02
	S.Ed	**(*P* <0.05)**	**S.Ed**	**(*P* <0.05)**	
Test Entries	1.9	4.0	1.3	2.8	
Checks	0.8	1.8	0.6	1.2	
Test V check	1.4	3.1	1.0	2.2	

S.Ed = Standard error of difference

Table 5. Yield and yield traits in sorghum germplasm collection exposed to drought stress

Genotypes	Control		Drought Stress		Percentage reduction	
	Grain yield (g/plant)	TDMP (g/plant)	Grain yield (g/ plant)	TDMP (g/plant)	Grain yield (%)	TDMP (%)
TKSV 1036	38.60	160.00	34.05	150.00	11.80	6.25
TKSV 1146	20.78	120.00	13.15	97.00	36.70	19.16
TKSV 1158	22.80	117.00	14.72	95.00	35.40	18.80
TKSV 1704	33.80	148.00	23.74	130.00	10.05	12.16
TKSV 1707	37.30	159.00	32.00	148.00	14.20	6.91
TKSV 1712	29.00	130.00	32.00	116.00	17.30	10.76
TKSV 1801	33.40	151.00	23.97	145.00	12.90	3.97

Genotypes	Control				Drought Stress				Percentage reduction	
	Grain yield (g/plant)		**TDMP (g/plant)**		**Grain yield (g/ plant)**		**TDMP (g/plant)**		**Grain yield (%)**	**TDMP (%)**
TKSV 1802	30.84		146.00		26.98		141.00		12.50	2.75
K8	29.28		144.00		25.44		140.00		13.10	2.77
PEC 5	32.70		144.00		23.28		127.00		28.80	4.38
PEC 12	31.20		154.00		23.18		136.00		25.70	11.68
PEC 14	45.20		167.00		36.10		156.00		13.70	6.58
PEC 16	34.00		146.00		24.20		129.00		28.80	11.64
PEC 17	59.40		177.00		50.75		170.00		12.50	3.95
PEC 22	28.00		116.00		22.50		103.00		19.60	11.20
PEC 23	34.10		150.00		24.99		134.00		26.70	10.66
PEC 24	28.50		129.00		23.00		114.00		19.30	11.62
PEC 31	41.80		167.00		36.10		153.00		13.60	8.38
PEC 32	28.50		156.00		24.23		139.00		15.00	7.33
PEC 33	26.40		110.00		21.54		106.00		18.40	3.68
PEC 34	53.32		173.00		46.00		166.00		13.70	4.04
PEC 35	28.20		127.00		22.36		111.00		20.70	11.62
PEC 36	29.70		121.00		25.55		110.00		14.00	4.34
EN 55	15.40		108.00		9.46		88.00		38.50	18.51
EP 72	17.00		112.00		10.02		90.00		41.00	19.64
EP 87	21.66		115.00		12.21		93.00		43.60	19.13
EP 90	48.70		172.00		42.11		158.00		13.50	8.13
EP 93	26.80		118.00		21.72		109.00		19.00	2.79
EP 94	30.40		126.00		24.64		120.00		18.90	4.76
M 35-1 (check 1)	80.00		192.00		72.00		185.00		10.00	3.64
K 12 (check 2)	70.00		187.00		61.00		181.00		12.90	3.20
CSV-27 (check 3)	66.40		182.00		58.00		176.00		12.70	3.29
CSV-29-R (check 4)	61.00		179.00		53.40		174.00		12.50	2.79
	S.Ed	**(*P* <0.05)**	**S.Ed**	**(*P* <0.05)**	**S.Ed**	**(*P* <0.05)**	**S.Ed**	**(*P* <0.05)**		
Test Entries	1.6	3.6	3.3	7.0	1.1	2.4	2.1	4.4		
Checks	0.7	1.1	1.4	3.1	0.5	1.1	0.9	2.0		
Test V check	1.3	2.7	2.4	2.4	0.9	1.9	1.6	3.4		

S.Ed = Standard error of difference

3.1.2 Leaf area (cm^2/plant)

Before imposing drought stress leaf area was measured highest (499.89cm^2/plant) in PEC5 and lowest (130.24 cm^2/plant) in TKSV 1712 (Table 2). Leaf area ranged from 189.05 cm^2/plant to 399.40 cm^2/plant under drought stress (Table 4).The genotype M 35-1recorded higher leaf area (399.40 cm^2/plant) compared to other three checks under drought stress. Considering all twenty nine genotypes, PEC 17 was having higher (383.99 cm^2/plant) leaf area followed by PEC 34(365.90 cm^2/plant), EP 90 (363.05 cm^2/plant), PEC 14 (350.08 cm^2/plant) under drought stress. Lesser leaf area was observed in EN 55 (189.05 cm^2/plant) followed by EP72 (198.60cm^2/plant) and EP 87 (200.96cm^2/plant) under drought stress. Leaf area exhibited highly significant and positive correlation with grain yield, plant height and chlorophyll index (Table 6).

3.1.3 Chlorophyll index

Chlorophyll index of all the genotypes was recorded after imposing drought stress. Chlorophyll index ranged from 28 to 62 under the drought stress (Fig. 1). Among the checks, M35-1 measured higher chlorophyll index (62.00) under drought stress. Among the genotypes, PEC17recorded higher chlorophyll index (55.89) followed by PEC 14 (64.8) and PEC 31 (48.00), whereas the genotypes EN 55 (30.52), EP 72 (28.67) followed by EP 87(28.00) recorded lower chlorophyll index under drought stress. Chlorophyll index unveiled highly significant and positive correlation with yield traits grain yield, leaf area and plant height (Table 6).

3.1.4 Ear head length (cm)

Ear head length of all the genotypes was recorded after imposing drought stress. Ear head length ranged from 9.80 to 28 cm under the drought stress (Fig. 2). Among the checks, M35-1 recorded longer ear head length (28 cm) under drought stress. Among the genotypes, PEC 17 was recorded with longer ear head length followed by PEC 14 (25.99 cm) and PEC 31 (25.68 cm), whereas the genotypes EN 55(9.80 cm), EP 72 (10.50 cm) followed by EP 87 (11.90 cm) were recorded with shorter ear head length under drought stress. Ear head length exhibited highly significant and positive correlation with grain yield (Table 6).

Table 6. Correlation of morpho-physiological traits and yield components in sorghum germplasm under drought stress

	Grain yield	Plant height	Leaf area	Total dry matter production	Harvest Index	Chlorophyll index	Ear head weight	Ear head length
Grain yield	1							
Plant height	0.775**	1						
Leaf area	0.760**	0.669**	1					
Total dry matter production	0.908**	0.703**	0.770**	1				
Harvest Index	0.971**	0.775**	0.722**	0.832**	1			
Chlorophyll index	0.958**	0.797**	0.822**	0.936**	0.917**	1		
Ear head weight	0.844**	0.693**	0.698**	0.888**	0.850**	0.853**	1	
Ear head length	0.830**	0.665**	0.705**	0.928**	0.789**	0.856**	0.918**	1

*** indicate significance @ P≤0.001%*

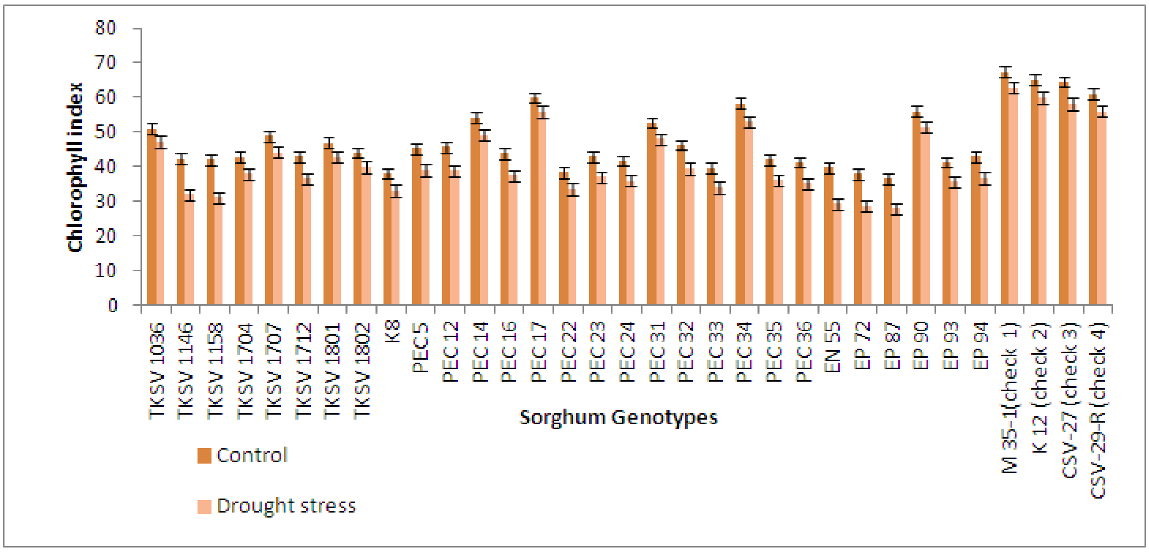

Fig. 1. Alteration in chlorophyll index in sorghum germplasms at 50% drought stress

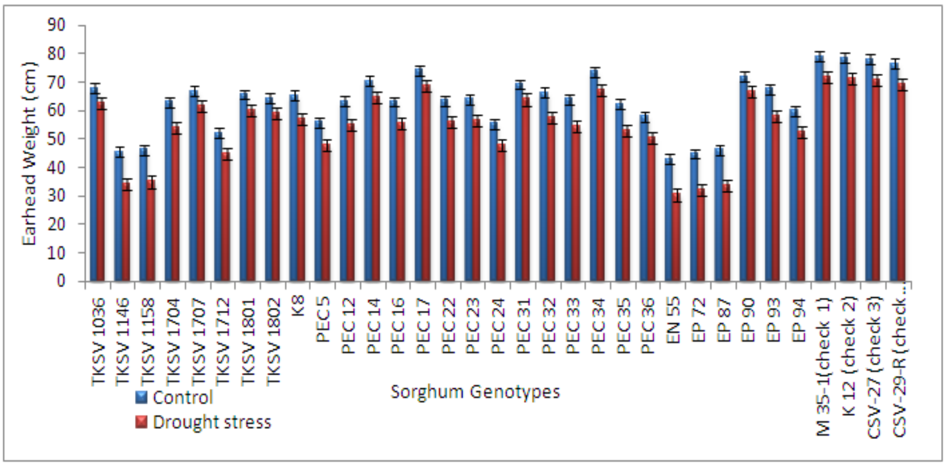

Fig. 2. Effect of drought stress on ear head weight in sorghum germplasm

3.1.5 Ear head weight (g)

Ear head weight of all the genotypes was recorded after imposing drought stress. Ear head weight ranged from 30.42 g to 72 g under the drought stress (Fig. 2). Among the checks, M35-1 recorded higher ear head weight of 72 g under drought stress. Among the genotypes, PEC 17 (26.40 g) recorded higher ear head weight (68.82 g) followed by PEC 14 (64.82 g) and PEC 31 (64 g), whereas the genotypes EN 55 (30.42 g), EP 72 (32.07 g) followed by EP 87 (33.50 g) were recorded with lower ear head weight under drought stress. Ear head weight exhibited highly significant and positive correlation with grain yield and TDMP (Table 6).

3.2 Yield and Yield Components

3.2.1 Grain yield (g / plant)

The grain yield ranged from 9.46 g/plant to 38.92 g/plant under the drought stress (Table 5). Among the four checks, M35-1 recorded higher grain yield (72g) under drought stress whereas, among the 29 genotypes, PEC 17 had higher grain yield (50.75g) under drought stress followed by PEC 14 and PEC 31, TKSV 1036. The poor yielders under drought stress was EN 55 (9.46g) followed by EP 72 (10.02 g) and EP 87 (12.21 g). Grain yield had a highly significant and positive correlation with plant attributes such as plant height, leaf area, and total dry matter production, harvest index, chlorophyll index, ear head weight and ear head length (Table 6).

3.2.2 Total Dry Matter Production (TDMP) (g/plant)

TDMP ranged from 88 g/plant to 185 g/plant under the drought stress (Table 5). Among the four checks M35-1recorded higher TDMP (185g/plant) under drought stress. Among the genotypes, PEC 17 recorded higher TDMP (170g/plant) followed by PEC 14, PEC 31 and TKSV 1036 whereas, lower TDMP was recorded in EN 55 (88 g/plant), EP 72 (90 g/plant) and EP 87 (93 g/plant). TDMP exhibited highly significant and positively correlation with grain yield (Table 6).

3.2.3 Harvest index

Harvest index was found to be reduced under drought stress compared with the control plants and it ranged from 10.75 to 38.92 under drought stress (Fig 4). Among the checks M35-1 recorded highest harvest index (38.92) under drought stress. The genotype PEC 17 was recorded with more harvest index (29.85) followed by PEC 14 (25.01) and PEC 31(23.59) whereas, the genotypes EN 55 (10.75), EP 72 (11.14) followed by EP 87 (13.13) were recorded with lower harvest index. The harvest index exhibited highly significant and positive correlation with grain yield and TDMP (Table 6).

4. DISCUSSION

4.1 Morpho-physiological Traits

4.1.1 Plant height

Plant height is considered as a crucial trait, when determining drought tolerance. Before imposing drought stress PEC 36 had higher plant height (250 cm) and CSV-27 (140 cm) had lower plant height (Table 2). Similar to the above findings plant height was higher in control compared to drought stress plants [18]. Highest mean plant height was recorded under well watered plants [15]. After imposing drought stress, M35-1(313.66 cm) had taller plants under control, in case of drought M 35-1 (287.60 cm) had shorter plants (Table 3). M 35-1 was a taller check and it showed minimum percentage reduction (8.31%) of plant height under drought stress (Table 3). Among genotypes EP 90 (5.46%) had less reduction followed by PEC 34 (6.34%), PEC 17 (6.76%) whereas higher percentage reduction was reported in EN 55 (41.78%) followed by EP 72 (37.25%), EP 87 (24.84%). Water deficiency slows cell expansion and cell size, followed by growth rate and stem elongation [19].

4.1.2 Leaf area

Before imposing drought stress PEC 5 (499.89 cm^2/plant) had maximum leaf area and minimum leaf area was measured in TKSV 1712 (130.24 cm^2/plant) (Table 2). Leaf area was recorded maximum under well watered condition and was decreased under drought where leaf area of three sorghum cultivars reported the reduction of 28%, 54% and 63% respectively. Control conditions recorded higher leaf area [20]. After the drought stress imposition, M 35-1 showed maximum (429.31 cm^2/plant) leaf area under control, whereas leaf area was decreased (399.40 cm^2/plant) with minimum percentage of reduction (6.97%) (Table 4). Among genotypes PEC 17 (6.53%) had lesser percentage reduction followed by TKSV 1802 (6.75%), TKSV 1036 (7.10%) and higher reduction was reported in EP 87 (40.87%) followed by EP 72 (37.65%), EN 55 (34.27%) (Table 4). Similarly [21], observed reduction in leaf area as a result of drought. However, the decrease in leaf area that is typically seen in plants is a drought-avoidance strategy that prevents cell proliferation and reduces water loss [22].

4.1.3 Chlorophyll index

Among checks M 35-1 (67.40) measured higher chlorophyll index under control whereas chlorophyll index was decreased under drought (62.87) with less percentage reduction of (6.72) (Fig 1). Considering genotypes PEC 17 (6.83%) reported less percentage reduction in chlorophyll index followed by TKSV 1036 (7.45%), EP 90 (7.94%) and higher reduction was reported in EN 55 (26.32%) followed by EP 72 (24.55), EP 87 (23.51%) (Fig 1). The amount of chlorophyll is an important key factor in choosing genotypes for drought tolerance and generally chlorophyll content decreases under drought stress [23]. The results of the study are in line with findings where chlorophyll content was reduced highest (40%) and lowest (17%) under water limitation conditions [24].

4.1.4 Ear head length

The cultivar M35-1 recorded longer ear head length (30.43 cm) under control and under drought stress it reported shorter ear head length (28 cm) with minimum percentage of reduction (7.98%) (Fig. 3). In case of genotypes, minimum percentage reduction in ear head length was recorded in TKSV 1707 (4.61%) followed by TKSV 1036 (6.29%), PEC 34 (6.64%), whereas the genotypes which reported maximum reduction in percentage were EN 55 (29.89%) followed by EP 72 (25.00%) and EP 87 (24.34%). In line with the above findings, minimum ear head length was observed under 25% moisture regime [15]. Under low irrigation facility sorghum hybrid recorded very short ear head length (8 cm) [25]. Similarly decrease in ear head length and weight in rabi sorghum was observed when exposed to water deficit conditions [15].

4.1.5 Ear head weight

The ear head weight was measured higher in M 35-1 (79.11g) under control, whereas under drought it measured lower ear head weight (72 g) with minimum percentage of reduction (8.98%) (Fig. 2). In case of genotypes, PEC 17 (7.26%) recorded minimum reduction percentage followed by EP 90 (7.30%) and PEC 31 (7.64%), whereas EN 55 (29.25%), followed by EP 72 (28.59%) EP 87 (27.48%) recorded maximum reduction in percentage and minimum ear head weight (63.42 g) was observed in 25% moisture regime as reported by Pawar and Gagakh [15]. Similar findings were reported by Talwar [26] where significant reduction in ear head weight was measured under non - irrigated conditions. Prolonged drought results in fewer and smaller ear heads was mentioned by Robinson et al. [27].

4.2 Yield and Yield Components

4.2.1 Grain yield

The cultivar M 35-1(80.00 g) had higher yield under control, as well as in drought stress M 35-1 (72 g) with minimum percentage of yield reduction (10%) (Table 5). Genotypes TKSV

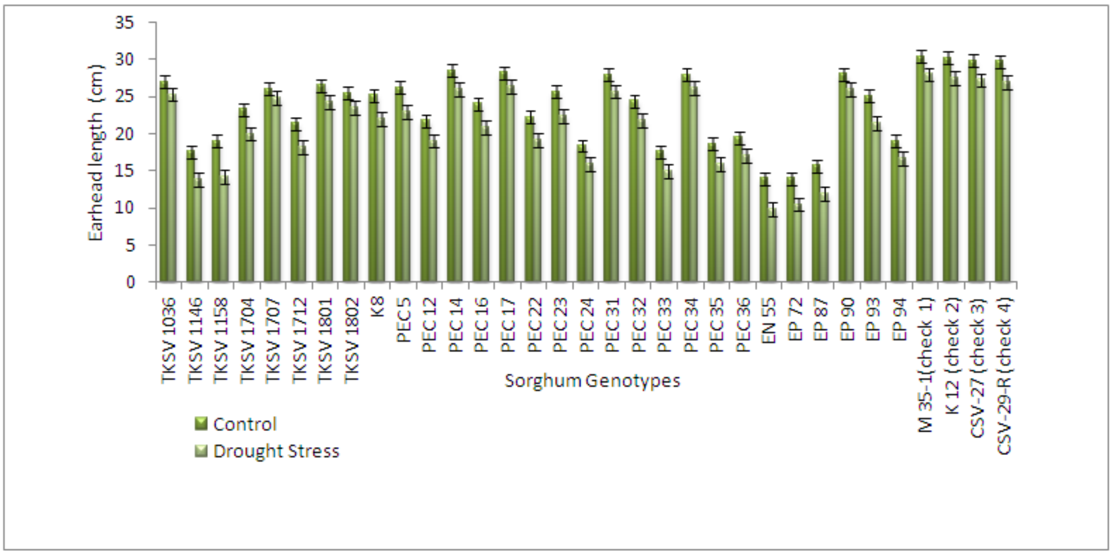

Fig. 3. Influence of drought stress on ear head length in sorghum germplasm collections

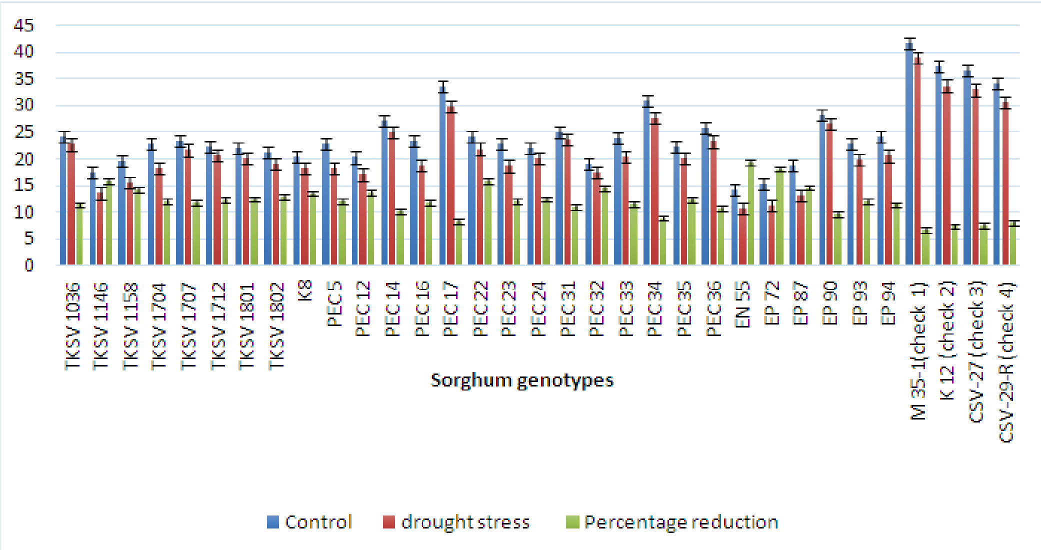

Fig. 4. Influence of drought stress harvest index in sorghum germplasm collections

1036 (11.8%) had lower percentage reduction of grain yield followed by TKSV 1802 (12.5%) TKSV 1801 (12.9%) whereas higher reduction was observed in EP 87 (43.6%), followed by EP 72 (41.0%) and EN 55 (38.5%). Grain yield and water have a complicated relationship because yield is susceptible to water shortages during drought sensitive stages [28]. This is in line with the findings of Sweeten and Jordan [29] where by withholding 100 millimetres of irrigation water at 6 to 8 leaf stage and at heading, blooming stage grain yield reduced by 10 and 50% respectively. Drought stress imposition from germination to booting stage reduced the grain yield more than 50% in three consecutive years [18]. Grain yield was found to be positively correlated with plant height, leaf area, chlorophyll index, total dry matter production, harvest index, ear head weight and ear head length (Table 6). Similar findings were obtained in rabi sorghum where, grain yield per plant was found to be strongly and positively correlated with ear head length, seed weight, and harvest index [30].

4.2.2 Harvest index

Harvest index, is regarded as a crucial factor in the selection of genotypes with high yields [31].

Genotypes PEC 17 (8.1%) had lower reduction of harvest index followed by PEC 34 (8. 9%), EP 90 (9.7%) whereas, higher percentage reduction was found in EN 55 (19.27%) followed by EP 72 (18.1%), TKSV 1146 (15.86 %) (Fig. 4). These findings are in line with the results of Mutava et al. [24], where harvest index decreased by 46% and 60 % under drought conditions. Similarly [32] observed severe reduction of harvest index under water deficit stress in sorghum genotypes under greenhouse and field experiments and a study by Patil [16] also reported a decrease in harvest index in winter sorghum.

4.2.3 Total Dry Matter Production (TDMP)

Total dry matter production showed significant reduction during water deficit conditions. Check variety M 35 -1 showed less TDMP (185 g) with minimum percentage reduction (3.6%) under stress (Table 5). Close to checks, PEC 17 (2.7%) had less reduction percentage followed by PEC 34 (3.9%), EP 90 (4.0%) and higher reduction was reported in TKSV 1146 (19.16%), EP 87 (19.13 %) and TKSV 1158 (18.80%). Total dry matter production reduces under drought conditions [33]. Similarly, dry matter production was decreased at post-anthesis stage in terminal water deficit condition in nine sorghum hybrids under three water regimes [34].

5. CONCLUSION

The present investigation attempted to impose a stress at for 2 weeks during booting stage till half bloom stage. Significant reduction in all the morpho-physiological traits were observed. Grain yield was found to be highly significant and positively correlated with other traits. To present, the most of drought-tolerant sorghum selections appear to be focused on developing a cultivar that produces more grain from a given amount of water. The existence of heterogeneity among types and the significance of water usage efficiency are undeniable.Among ICAR-IIMR sorghum germplasm collections screened for drought stress tolerance PEC 14, PEC 17, PEC31, PEC 34 EP 90 showed drought tolerance on par with the checks. Similarly, TKSV 1036, TKSV 1707, TKSV 1801, TKSV 1802 germplasm from ARS, Kovilpatti were tolerant to drought stress at booting stage. Minimum percentage reduction (4-10%) was observed in tolerant germplasms. Similarly, maximum percentage reduction (19-43%) was recorded in drought sensitive germplasms. Further, it is concluded that the traits *viz*., plant height, leaf area, chlorophyll index, ear head weight, grain yield, total dry matter production, harvest index are the noteworthy to study in sorghum for drought screening.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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