International Journal of Tropical Agriculture
Volume 39, Number (4) • 2021 : pp. 483-490
ISSN: 0254-8755

SCREENING OF DROUGHT TOLERANT HIGH YIELDING RABI SORGHUM (*SORGHUM BICOLOR* L.) GERMPLASM GENOTYPES BASED ON MORPHO-PHYSIOLOGICAL TRAITS

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Abstract: Sorghum is the most drought-resistant among the world's top five cereal crops, and an important dual-purpose crop. In sorghum, drought can occur at pre-flowering and grain filling stages of the plant development. At seedling stage, severe drought stress would affect plant stand and survivability. Forty four sorghum lines including checks were screening for drought tolerance on physiological basis at Regional Agricultural Research Station, Vijayapur during rabi season 2020-21. The resultant of 41 lines in comparison to checks indicated that, genotype SVD 1210 (70 days), RNTN-13-23 (70 days) and VJP 303 (71 days) recorded early flowering. RSV 2408 (110 days) recorded early maturity followed by VJP 301 (111 days). Further, leaf area and leaf area index was significantly higher in RSV 2011 (1637 cm^2 and 3.94 respectively). Maximum SAPD values were recorded in VJP 311 (51.12) followed by check P. Anuradha (50.06) and VJP 301 (50.00). Dry matter partitioning at 50% flowering was significantly higher in VJP 306 (71.00 g $plant^{-1}$). However, at physiological maturity RSV 2011 recorded maximum biomass (162.32 g $plant^{-1}$) which was on par with AKSV 401 R (161.39 g $plant^{-1}$). Genotype SVD 1210 recorded maximum test weight (36.63 g). Genotype RSV 2011 (62.69) recorded significantly higher grain yield per plant which was on par with AKSV 401 R (62.58) compared to check M 35-1 (49.48). Both the genotypes RSV 2011 and AKSV 401-R recorded higher grains per panicle (1799 and 2179 per panicle respectively and dry fodder weight (149 and 131 kg ha^{-1}). The experiment concluded that, based on physiological traits, RSV 2011, AKSV 401 R, RNTN 13-8, CRS 96, SVD 1433, VJP 307 and VJP 310 were identified as drought tolerant and can be further sorghum crop improvement programme.

Key words: drought, biomass, leaf area, leaf area index, test weight, grain yield

INTRODUCTION

Grain sorghum (*Sorghum bicolor* L. Moench) has its origins in Africa, is the fourth most important cereal crop after wheat, rice, and maize, and is now grown throughout the semiarid tropical and semiarid temperate regions of the world. From the time the domestication of sorghum commenced, around 4,000-3,000 BC, numerous varieties have been developed through farmer selection. These improved sorghum types spread through the movement of people and trade routes into other regions of Africa, India (approx. 1500-1000 BC) and the Middle East (approx. 900-700 BC). (Mutava, 2009).

Karnataka ranks 2^{nd}in terms of area and production with 0.81million hectares (2019-20) area under production comprising 17.23% of India's sorghum growing area by producing 1.03 million tonnes per annum (2019-20) accounting for 21.75% of India's total sorghum production. Karnataka's productivity is 1268 Kg/Hectare. The area under rabi sorghum in Karnataka is 6.99 lakh hectares (2019-20). Rabi sorghum production is 8.1 lakh tonnes and productivity is

Article History: Received: 29 November 2021; Revised: 5 December 2021; Accepted: 21 December 2021

1159 Kg ha^{-1} in Karnataka (2019-20). (Directorate of Economics and Statistics, 2020).The third advance estimates done on 25 May 2021 by the Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare show that rabi sorghum production may reach 2.89 million tonnes.

Sorghum is the most drought-resistant among the world's top five cereal crops, and an important dual-purpose crop. Sorghum cultivation ranges from the equator (approximately 50° latitude) to elevations of 2500 m. In India it is mostly spread between 9°N and 21°N latitudes. (Rao, 2020). Sorghum is exceptionally tolerant to low input levels, which is an important characteristic for the areas receiving little rainfall. The plasticity of overall growth and development in response to changing moisture and nutrient status of the soil provide opportunities for exploring natural variation to identify beneficial root traits to enhance plant productivity in agricultural systems (Ashok Badigannavar, 2018) In sorghum, two distinct drought-stress responses have been identified based on the time of occurrence: a pre-flowering drought response occurring prior to anthesis and a post-flowering drought response during the grain-filling stage (Harris, 2007).Water stress in plantsmay manifest as decreased leaf water content and chlorophyll contents. The leaf water content is a measure of plantstress and severe decreases may contribute to structural interruptionsof important biological functions in plants leading to injury or tissue death (McKersie and Leshem, 1994). Leaf area, chlorophyll pigments, leaf area index and partitioning of biomass are indicators of overall plant health and directly influence a plants' ability for photosynthesis (Malkin and Niyogi, 2000). This is crucial to maintaining vital processes of the plant system.This study was a drought experiment in which 44 sorghum Germplasm lines were chosen for preliminary evaluation for rabi adaptation traits with the objective to identify potential donors for genetic enhancement of rabi sorghumdrought tolerance.

MATERIALS AND METHODS

Plant material: The experiment was conducted at the Regional Agricultural Research Station, Vijayapur during *rabi* season 200-21. The Research Station is situated at 16°49' N latitude and 75°43' E longitude with an altitude of 593 meters above the mean sea level (MSL). Forty one *rabi* sorghum lines with three checks (M 35-1, PhuleAnuradha and PhuleSuchitra) were evaluated for drought tolerance in medium black soil. The germplasm lines were contributed from various all India coordinated research project on sorghum across India. Some of the contributing centres are MPKV Rahuri, AICSIP Vijayapur, Central research on sorghum Solapur, Maharashtra, Dharwad, IIMR Hyderabad and Tamil Nadu.

Field experiment: The sorghum genotypes were planted on first week of October in a triplicate Randomized Complete Block Design (RCBD) with experimental plots comprising of two rows, 3m long and 45cm apart. Four soil samples from each replication were taken for soil analysis. The planting was done with sufficient soil moisture (24%). Plots were treated alikefor all the cultural practices and nutrient application fromsowing till harvest. Meteorological data regarding minimum and maximum temperature, relative humidity, pan evaporation and monthly rain fall were taken through out the growing season. Patterns of rainfall (mm), temperature (ºC), relative humidity (%) and pan evaporation (mm) showed sufficient period for the crop to be exposed to water stress at booting, anthesis and post-anthesis stages (Fig. 1).

Observations recorded: To study the moisture regime of the experimental plots, soil moisture levels at every plot representing different generations across all the three replications were recorded at 0-15, 15-30 and 30-45 cm depth at the time of sowing, vegetative (45-50 days), flowering stage (70.75 days) and at harvest (115-120 days). Gravimetric methodwas carried out to determine soil moisture content. Observations on important drought tolerant traits suchas plant height (cm) at harvest, flowering and maturity, leaf area, LAI, SPAD and dry matter was recorded at 50% flowering. Biomass at harvest, test weight (g), grains per panicle, dry fodder (kg ha^{-1}) harvest index (%) and grain yield (g plant^{-1}) were recorded.

RESULTS AND DISCUSSIONS

Morphological and phenological parameters: Forty four *rabi* sorghum germplasm lines were tested for drought tolerance on morphological, physiological parameters, yield and yield components. The germplasm lines were contributed from various all India coordinated research project on sorghum across India. Some of the contributing centres are MPKV Rahuri, AICSIP Vijayapur, Central research on sorghum Solapur, Maharashtra, Dharwad, IIMR Hyderabad and Tamil Nadu. The entries were tested at Regional Agricultural Research Station, Vijayapura under medium black soil during 2020-21 *rabi* season. The station receives maximum rainfall during *rabi*season compared to *kharif* making ideal conditions for sorghum cultivation. The sowing of the crop was done on 40^{th} standard meteorological week (SMW) with prevailing T Max $31.04^{0}C$ and T min $21.09^{o}C$ as represented in table 1. The soil moisture recorded at initial stage was 21.59% at 0-15cm depth, 22.66% at 15-30 cm depth and 23.72% at 30-45 cm depth. Maximum rainfall was recorded at 38th SMW (95.8mm) followed by 39 SMW (79.2 mm). However sufficient amount of rainfall was received from 36^{th}SMW to 43^{rd}SMW. However, the crop experienced post flowering drought stress due to failure of rain after 44^{th}SMW. Making the suitable condition for screening the sorghum lines. The results indicated that, genotype CRS 97 (67 days) recorded significantly lesser day for 50 % flowering and for Physiological maturity (112 days) compared to checks M 35-1 (80 days) and Phule Anuradha (77 days). Genotypes identified for earliness are RNTN-13.23 (70 days), SVD 1210 (70 days), VJP 303 (71 days) and VJP 302 (72 days) with the physiological maturity ranging between 110 to 112 days. However days to 50% flowering ranged between 70-80 days and physiological maturity ranged between 110-120 days among the entries.Although grain sorghum exhibits resilience to the effects of water stress, particular growth stages (panicle initiation and flowering) in its lifecycle are susceptibleto drought stress(Wani*et al*., 2012). The early vegetative stage and reproductive stages such as pre- and post-flowering of sorghum are vulnerable to the effects of water deficit (Tuinstra *et al*., 1997; Kebede *et al*., 2001). A drought period during the early seedling stage of sorghum may inhibit establishment of the crop and exhibit earliness representing drought excape mechanism (McKersie and Leshem, 1994). The water demand of sorghum is greatest during the pre-flowering reproductive growth stage (Anon, 2008).The plant height profiles of the sorghum genotypes were noted during harvest when plants were measured from the soil surface to the top of sorghumstalk. Statistical analysis of height data showed a significant difference in the plant height profiles among the sorghum genotypes investigated. In the current investigation, genotype M 35-1 recorded significantly higher plant height (227 cm $plant^{-1}$) followed by RSV 2441 (221 cm $plant^{-1}$), RNTN-13-14 (216cm $plant^{-1}$), CRS 88 (214 cm $plant^{-1}$) and AKSV 401-R (213cm $plant^{-1}$). Generally, taller sorghum genotypes are favoured for cultivation and are primarily grown by small-scale farmers in Asia(Graham and Lessman, 1966; Liang *et al*., 1969). Tall genotypes are used as fuel and building material after grain harvest (Maiti*et al*., 2012). It is previously reported that, the performance of sorghum is found to have a strong correlation between increased plant height and grain yield (Jordan et al, 2003). George-Jaeggli *et al.* (2011) reported that increased biomass of tall sorghum plants was important for increased grain yield after investigating the direct effects of a major dwarfing gene on sorghum shoot biomass, grain yield, and yield components. In the present investigation the partitioning of assimilates were recorded at 50% flowering and at harvest. The biomass partitioning differed significantly among the genotypes. The biomass accumulation is strongly positively associated with the yield potentiality of the genotype. Among the 44 genotypes tested, VJP 306 (71.00g plt) which was on par with VJP 310 (69.22) and check variety M 35-1 (68.47) at 50% flowering. However, at the physiological maturity, genotype RSV 2011 (102.32) recorded significantly higher biomass accumulation followed by AKSV 401-R (161.39) compared to check M 35-1 (111.23).

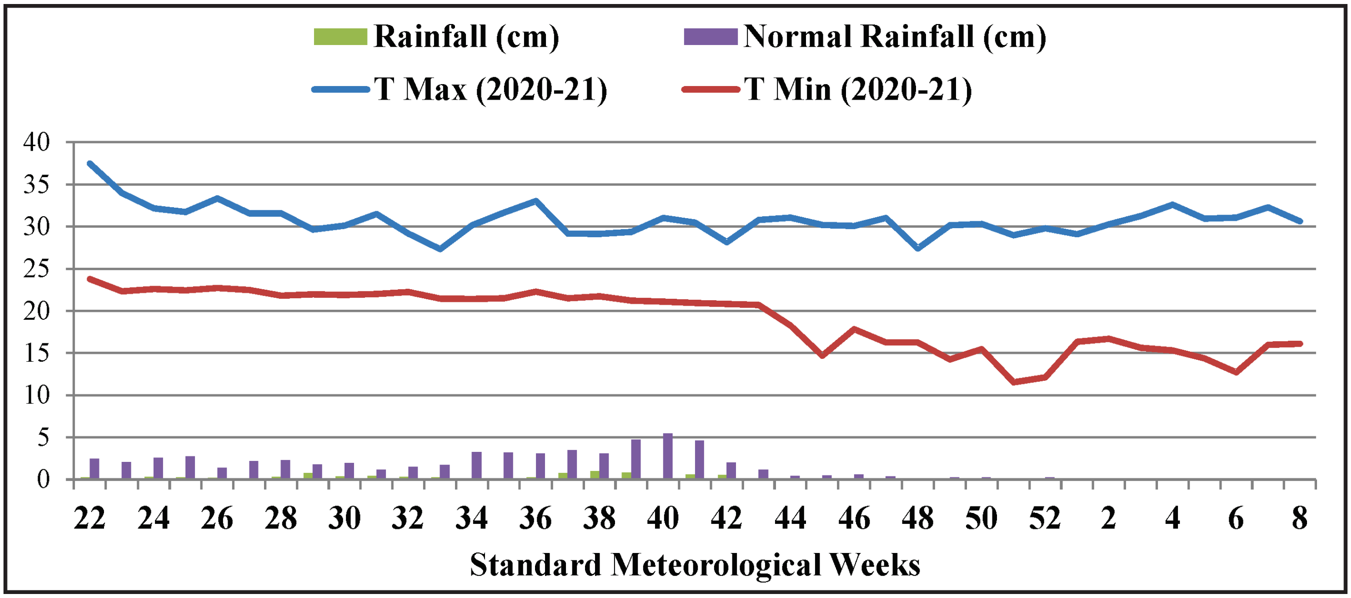
Physiological parameters: Some of the physiological traits such as green leaf area, leaf area index, SPAD values and dry matter

Table 1: Summary Statistics for different *rabi* sorghum genotypes, phenology, physiological traits and biomass.

	Genotypes	*Plant Height (cm)*	*Days to 50% Flowering*	*Days to Physiological maturity*	*Leaf area (cm^2)*	*LAI*	*SPAD*	*Total matter at flowering*
1	RSV 1988	196	75	118	1006	2.16	41.88	45.38
2	RSV 2011	194	83	121	1637	3.94	44.65	60.50
3	RSV 2095	206	74	112	1151	3.06	46.42	40.54
4	RSV 2115	208	74	113	1356	3.52	39.17	45.91
5	RSV 2357	209	79	119	1127	3.42	46.15	40.75
6	RSV 2371	191	73	114	1342	3.63	49.50	45.53
7	RSV 2397	219	76	116	851	2.01	43.15	43.05
8	RSV 2408	202	75	110	1035	2.18	41.65	57.83
9	RSV 2422	187	77	119	860	2.01	41.37	41.13
10	RSV 2441	221	84	125	1127	3.23	44.94	47.04
11	RSLG 2438	189	85	124	1174	2.33	41.87	37.68
12	VJP 301	204	72	111	1177	2.58	36.80	39.10
13	VJP 302	192	72	114	1247	3.47	40.90	46.83
14	VJP 303	207	71	119	1188	2.63	38.80	49.48
15	VJP 305	176	77	120	981	1.81	45.48	31.90
16	VJP 306	193	74	117	1265	3.38	44.13	71.00
17	VJP 307	201	79	118	1448	3.69	50.00	49.99
18	VJP 308	160	79	117	1354	3.58	44.13	46.27
19	VJP 309	183	74	114	1150	2.98	41.75	43.44
20	VJP 310	202	80	119	1632	3.77	48.53	69.22
21	VJP 311	209	77	119	1342	3.55	51.12	64.69
22	VJP 2703	179	83	123	1290	3.36	46.21	63.03
23	SVD 1210	202	70	111	1682	3.56	48.07	59.98
24	SVD 1433	201	77	119	1637	3.81	42.54	54.07
25	VJP 304	196	78	117	924	2.15	43.33	37.41
26	CRS 88	214	82	122	1215	3.53	43.30	34.02
27	CRS 96	190	73	115	1514	3.77	37.84	37.75
28	CRS 97	177	67	112	1052	3.31	41.34	41.13
29	CRS 100	197	79	121	1147	2.78	35.10	42.85
30	CRS 101	213	76	111	1140	3.24	41.59	48.04
31	CRS 102	175	74	113	1159	2.32	34.79	52.63
32	CRS 103	192	76	116	975	1.85	39.23	41.75
33	CRS 104	214	81	119	875	2.03	42.23	33.19
34	AKSV 401-R	213	78	120	1430	3.87	45.01	61.02
35	AKSV-252-R	159	79	120	832	2.08	47.61	48.88
36	RNTN-4-132	169	75	113	1259	3.34	39.88	53.56
37	RNTN-13-8	167	71	113	1410	3.79	48.50	52.29
38	RNTN-13-10	193	76	118	1584	3.48	44.20	37.40
39	RNTN-13-14	216	78	117	1027	2.21	47.55	46.28
40	RNTN-13-23	195	70	113	1003	2.15	35.85	53.83
41	RNTN-13-61	187	84	124	1002	1.98	42.30	44.56
42	M-35-1	227	80	116	1247	3.46	49.94	51.51
43	P. Suchitra	208	74	116	1375	3.48	47.18	68.47
44	P. Anuradha	180	77	118	1040	2.59	50.06	58.71
	Mean	195	76	116	1210	2.98	43.46	48.14
	S.Em. ±	3.53	1.18	0.51	58.37	0.08	2.42	1.02
	CD @5%	9.94	3.30	1.44	164.11	0.23	6.81	2.86

Trial 2: Summary Statistics for different *rabi* sorghum genotypes, yield and yield associated traits.

	Genotypes	*Total dry matter at Maturity*	*Test weight (g)*	*Harvest Index (%)*	*Grain yield (g plant⁻¹)*	*Dry fodder (Kg Ha⁻¹)*	*Grains / panicle*
1	RSV 1988	85.56	29.70	35.66	30.65	76	1046
2	RSV 2011	162.32	35.17	38.81	62.69	149	1799
3	RSV 2095	96.30	31.40	33.87	32.69	86	1050
4	RSV 2115	117.18	31.30	41.94	49.41	107	1574
5	RSV 2357	114.15	30.80	29.10	33.23	106	1081
6	RSV 2371	119.27	26.30	38.81	46.33	99	1765
7	RSV 2397	77.23	26.63	15.63	12.17	67	464
8	RSV 2408	82.15	29.07	28.11	23.13	72	806
9	RSV 2422	96.83	21.80	14.02	13.59	87	623
10	RSV 2441	103.41	25.63	31.90	33.03	93	1291
11	RSLG 2438	98.93	25.80	23.57	23.33	89	918
12	VJP 301	98.81	33.67	24.81	24.54	89	741
13	VJP 302	103.90	31.57	36.08	37.61	94	1189
14	VJP 303	100.82	33.30	25.80	26.13	91	804
15	VJP 305	71.62	27.63	11.64	8.40	62	309
16	VJP 306	98.04	30.73	35.37	34.72	88	1133
17	VJP 307	150.53	32.70	36.06	54.29	141	1662
18	VJP 308	123.84	25.87	37.95	47.00	104	1837
19	VJP 309	105.85	27.50	26.91	28.49	96	1050
20	VJP 310	142.24	34.67	36.36	51.69	112	1499
21	VJP 311	115.43	28.67	39.58	45.69	105	1594
22	VJP 2703	100.95	33.93	34.62	35.05	91	1039
23	SVD 1210	147.79	36.63	34.94	51.69	138	1417
24	SVD 1433	147.48	31.10	37.25	54.98	143	1847
25	VJP 304	80.35	23.30	18.59	15.01	70	655
26	CRS 88	124.60	32.70	35.89	44.71	115	1373
27	CRS 96	149.41	25.77	37.61	56.17	122	2185
28	CRS 97	111.58	33.77	30.80	35.17	102	1033
29	CRS 100	112.37	30.57	25.12	28.31	102	930
30	CRS 101	99.50	24.40	34.38	34.22	89	1408
31	CRS 102	92.69	29.63	25.09	23.29	83	793
32	CRS 103	79.24	24.97	10.90	6.46	69	266
33	CRS 104	100.71	27.23	14.52	14.77	91	553
34	AKSV 401-R	161.39	28.80	38.83	62.58	131	2179
35	AKSV-252-R	85.80	27.10	18.47	15.90	76	592
36	RNTN-4-132	111.63	31.50	30.82	34.41	102	1092
37	RNTN-13-8	151.15	25.73	37.81	57.08	133	2244
38	RNTN-13-10	113.08	19.17	34.37	38.63	103	2017
39	RNTN-13-14	87.28	28.17	25.43	22.29	77	789
40	RNTN-13-23	89.70	28.37	22.05	20.15	80	715
41	RNTN-13-61	72.00	30.67	12.55	9.32	62	312
42	M-35-1	111.23	36.90	35.35	39.34	101	1072
43	P. Suchitra	140.20	24.77	35.25	49.48	99	2029
44	P. Anuradha	92.22	25.67	28.37	26.16	82	1028
	Mean	109.66	29.23	29.55	33.91	97.14	1177
	S.Em. ±	3.40	1.74	1.88	2.56	5.35	114.72
	CD @5%	9.57	4.90	5.29	7.19	15.05	322.52



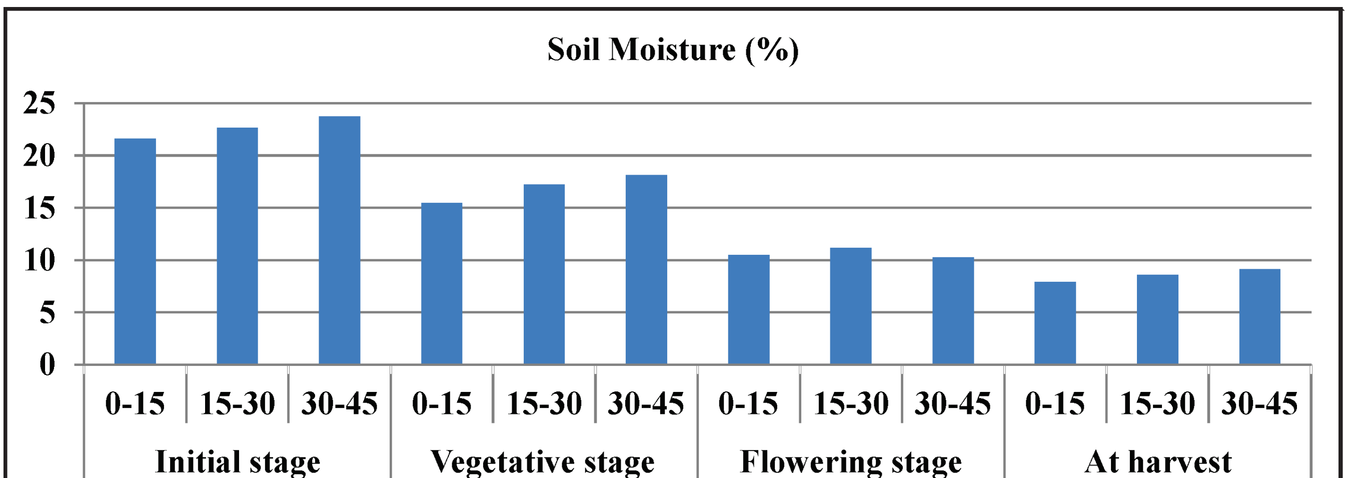


Fig. 2 Soil moisture at different stages and varied depths in sorghum genotypes during croping season.

Figure 1: Weekly meteorological data of rainfall, maximum and minimum temperature for 2020-2021 during crop growth period

partitioning were recorded at 50% flowering. Among the germplasm entries, the lines from AICSIP Dharwad recorded significant higher leaf area *viz*. SDV 1210 (1682 cm^2/plant) and SDV 1433 (1637 cm^2/plant) followed by lines from MPKV RahuriRSV 2011 (1637 cm^2/plant) which also recorded higher leaf area index (3.94) and lines from AICSIP Vijayapur VJP 310 (1632 cm^2/plant) with LAI of 3.77. The genotypes with better leaf area ranged from 1450 cm^2/plant to 1650 cm^2/plant and leaf area index from 3.90 to 3.70 at 50% flowering. Although leaf area is the ideotypic character of the plant, however the in decrease in leaf area in sorghum plant is primarily due to less elongation and enlargement of cell, coupled with lower the photosynthetic rate [1, 5, 6,].Leaf area is the main yield determining factor under receding soil moisture environment in northern dry zone of Karnataka [2].This intern has a greater influence on leaf area index because of its strong positive correlation.

The chlorophyll based SPAD values plays a key role in improving drought tolerance of post-rainy sorghum varieties [7]. In the current investigation SPAD values ranged between 40-45 at 50% flowering. The SPAD chlorophyll readings are one of the important physiological traits for screening drought tolerance in rabi sorghum. Among the genotypes VJP 311 (51.12) recorded higher SPAD values compared to check variety M 35-1 (49.94). M 35-1 is known to be a drought tolerant because of its stay green trait and higher physiological performance with drought adaptive mechanisms. Lines VJP 307 (50.00) and Phule Anuradha (50.06) were found to be on par with each other with respective to SPAD values at 50% flowering. It's an indicator of the photo-synthetically active light-transmittance characteristics of the leaf, which is dependent on the unit amount of chlorophyll (chlorophyll density) per unit leaf area. Leaf chlorophyll content is also a key indicator of the physiological status of a plant [8]. The physiological traits such as SPAD values, relative water content of leaf tissue and total chlorophyll content indicated the efficacy of the genotype for better adaptation.

Yield and associated traits: The forty one*rabi* sorghum entries with contrasting traits were compared with 3 check varieties for drought tolerance. The grain yield exhibited significant difference among the entries. Genotype RSV 2011 (62.69) recorded significantly higher grain yield per plant which was on par with AKSV 401 R (62.58) compared to check M 35-1 (49.48). Both the genotypes RSV 2011 and AKSV 401-R recorded higher grains per panicle (1799 and 2179 per panicle respectively) and dry fodder weight (149 and 131 kg ha^{-1}). The other genotypes with better yield potential were RNTN 13-8 (57.08g plant^{-1}), CRS 96 (56.17g plant^{-1}), SVD 1433 (54.98g plant^{-1}), VJP 307 (54.29g plant^{-1}) and VJP 310 (51.69g plant^{-1}) compared to M 35-1 (39.34 g plant^{-1}), P.Anuradha (26.16 g plant^{-1}) and P. Suchitra (49.48 g plant^{-1}). Early maturing genotypes potentially recorded lower grain yield compared to medium and long duration. This is because drought escape by shortening the growing period is made at the expense of the crops genetic yield potential. Short cropping duration may not be an exclusive selection criterion *per se* because other factors may also be involved in affecting genotype performance under water deficit conditions (Blum *et al.*, 2005). Genotype M 35-1 (36.90 g) recorded maximum test weight followed by SVD 1210 (36.63 g) and RSV 2011(35.17 g).Genotype RNTN 13-8 recorded higher grains per panicle (2244) with test weight (25.73 g). The reduction in the test weight in some genotypes is may be due to significant reduction in the dry matter accumulation in leaves which might have failed to supply the required photosynthates to the reproductive parts and more precisely to the developing seeds (Nawaz, 1994). Genotype RSV 2115 (41.94%) recorded higher harvest index followed by VJP 311 (39.58%) and AKSV 401 R (38.83%).

CONCLUSIONS

Screening sorghum Germplasm lines for drought tolerance based on morpho-physiological traits revealed seven (RSV 2011, AKSV 401 R RNTN 13-8, CRS 96, SVD 1433, VJP 307 and VJP 310) germplasm lines maintained superior performance in comparison to a recognised drought-tolerant breeding lines. The physiological parameters evaluated under water deficit conditions indicated that these selected germplasm lines may be drought tolerant.The present investigated exhibited important drought tolerance characteristics which will be valuable for incorporation into breeding programmes. Molecular investigations to elucidate a full profile of possible drought-responsive mechanisms in selected sorghum genotypes are in progress.

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