Evaluating the Effects of Drought Stress on Biomass and Yield Traits in Sorghum Genotypes

Abstract

The study aimed to identify drought-tolerant sorghum genotypes by evaluating twenty sorghum genotypes over two *Rabi* seasons (2021-22 and 2022-23) under irrigated and rainfed conditions using a split plot design. Results showed that moisture stress significantly affected sorghum performance, including leaf and stem dry matter accumulation, grain yield per plant, stover yield, and harvest index. Among the genotypes, BJV-44 and M-35-1 exhibited the least decline in grain yield per plant under rainfed conditions, with yields of 76.17 and 73.50 g/plant, respectively, compared to irrigated conditions. Conversely, genotypes M 148-138 and Tandur L experienced the most significant reductions in grain yield per plant under rainfed conditions. Basavana pada exhibited the highest harvest index. The study concluded that BJV-44 and M-35-1 are drought-tolerant sorghum genotypes with relatively higher grain yields per plant under rainfed conditions, providing valuable insights into sorghum genotype performance and resource utilization in drought-prone regions.

Key words: drought, genotypes, grain yield harvest index and sorghum

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a globally important crop, often referred to as the "King of Millets" due to its large grain size compared to other millets. It is grown in both rainy (*kharif*) and post-rainy (*rabi*) seasons. The *rabi* crop is mainly for human consumption, while the *kharif* crop is utilized in animal feed, starch, and alcohol industries. India is a key sorghum producer, with Maharashtra, Karnataka, and Andhra Pradesh contributing 80% of the country's production, making up around 16% of the global total. Sorghum cultivation covers 4.38 million hectares in India, yielding 1.99 million tonnes in *kharif* and 2.83 million tonnes in *rabi*. *Kharif* sorghum exhibits higher productivity at 1210 kg/ha compared to *rabi* sorghum, which yields 1033 kg/ha (Indiastat, 2022). *Rabi* sorghum is particularly crucial in rainfed Peninsular India. However, drought-prone regions face challenges, as water stress negatively impacts sorghum's canopy development, assimilation rates and nutrient distribution (Mickelbart *et al*., 2015). Water stress reduces both grain number and size in sorghum, with the most significant yield drop occurring when drought coincides with the flowering and grain-filling stage (Rattunde *et al*., 2016). Hence, the present study aims to investigate the impact of water stress on sorghum's biomass and yield parameters.

2. MATERIALS AND METHODS

2.1 Experimental site

The field experiment was conducted in plot No. 126 of E-block, Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad. The MARS is situated at 15°12’ N latitude and 76°34’ E longitude with an altitude of 678 meters above the mean sea level (MSL).

2.2 Meteorological condition

In this study, conducted over two rabi seasons (2021-22 and 2022-23), the meteorological data, including rainfall (in millimeters), mean maximum and minimum temperatures (in degrees Celsius), and relative humidity (%), were collected from the Agrometeorological Observatory at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. During the 2021-22 season, the maximum temperature fluctuated between 28.1°C in November and December, peaking at 32°C in February, while in the 2022-23 season, it ranged from 28.9°C in October to 32.6°C in February. The mean maximum temperature was highest during the crop harvest month (February) and lowest during the initial stage of crop growth. In terms of relative humidity, the highest average observed during crop growth was 81.25% in November for both seasons, while the lowest was 47.35% in February 2021-22 and 45.8% in February 2022-23. Precipitation was limited to October and November during the crop growth period, with minimal or no significant rainfall from December to February. In the 2021-22 season, the highest average rainfall of 96.2mm occurred in November, while in the 2022-23 season, it was 208.6mm in October, with no rainfall recorded in January and February for both seasons. These extended dry spells during critical stages of crop development could have significant implications for crop productivity.

2.3 Experimental setup

Field research was conducted using twenty selected genotypes (Table 1) sourced from AICRP Sorghum at MARS, University of Agricultural Science, Dharwad, during the *rabi* seasons of 2020-21 and 2021-22. The experimental setup, situated at the Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad (15°12’ N latitude, 76°34’ E longitude, and 678 meters above mean sea level), utilized a split-plot design with two replications. Twenty sorghum genotypes were grown under two distinct moisture conditions, rainfed and irrigated. Rainfed plots received no irrigation after sowing, while irrigated plots were subjected to two additional irrigations at 35 and 65 days after sowing. The soil at the experimental site was identified as medium black soil, classified as vertic inceptisols, with a depth of 2-3 meters. Soil moisture content at different depths (0-15, 15-30 and 30-45 cm) was evaluated at various growth stages (initial, vegetative, flowering, and harvest) using the gravimetric technique, calculating moisture content based on the formula: (Fresh Weight - Dry Weight) / Dry Weight x 100 (Gardner, 1986).

Table 1: List of sorghum genotypes

Names of sorghum genotypes							
1	SVD-1272R	**6**	SPV-2217	**11**	Tandur L	**16**	M 148-138
2	SVD-1358R	**7**	CSV-216R	**12**	Phule Anuradha	**17**	Basavan moti
3	SVD-1528R	**8**	CSV-29R	**13**	Chitapur – L	**18**	Phule Vasudha
4	SVD-1403R	**9**	ICSR-15001	**14**	DKS- 35	**19**	BJV-44
5	SPV-486	**10**	Basavana pada	**15**	M-35-1	**20**	ICSR- 13025

2.4 Observations recorded:

2.4.1 Panicle Weight per Plant (g): The panicle weight per plant was determined by selecting three representative plants, collecting their panicle heads, and measuring their individual weights. The mean weight of the panicle heads was recorded in grams.

2.4.2 Grain Yield per Plant (g): Panicle heads were threshed, and the resulting cleaned average grain weight per head was quantified and expressed in grams.

2.4.3 Harvest Index (%): The Harvest Index (HI) is calculated by dividing the economic yield (in t/ha) by the biological yield (in t/ha) and then multiplying the result by 100 to express it as a percentage. Economic yield refers to the yield of the crop component that has economic value, typically grains, fruits, or tubers. In the case of sorghum, economic yield refers to the grain yield per plant. Biological yield, on the other hand, refers to the total above-ground biomass produced by the crop, including stems, leaves, and reproductive structures.The harvest index is indicative of the proportion of total biomass allocated to economic yield relative to the total above-ground biomass produced by the crop. A higher harvest index indicates greater efficiency in the conversion of biomass into economic yield (Borrell and Hammer, 2000).

HI (%) = (Economic yield / Biological yield) x 100.

2.4.4 Grain Yield (kg/ha): The weight of properly dried and cleaned seeds collected from a specific plot was measured in kilograms per plot and subsequently converted to kilograms per hectare.

2.4.5 Stover Yield (kg/ha): After harvesting the panicles, the plants in each net plot were cut at ground level and sun-dried. After drying, the dried plant weight was measured in kilograms per plot and subsequently converted to tons per hectare for assessment.

2.4.6 Drought Susceptibility Index (S): Calculated as 1 - (Ys/Yp) / D, where Ys represents yield under moisture stress, Yp is potential yield under controlled moisture conditions, and D is drought intensity (Fischer and Maurer, 1978).

2.4.7 Stress Tolerance Index (STI): Computed as (Yp x Ys) / $(Yp)^2$, with Yp representing potential yield under irrigated conditions, Ys as potential yield under rainfed conditions, and Yp as the mean yield of all genotypes under irrigated conditions (Fernandez, 1992).

2.4.8 Yield Stability Ratio (YS): Determined as (Grain yield under stress / Grain yield under control) x 100, according to Lewis (1954).

3. RESULTS AND DISCUSSION

3.1 Plant biomass:

The study assessed biomass accumulation in sorghum by measuring dry weight in panicles, leaves, and stems (Table 2). Leaf dry matter accumulation showed significant variation between irrigated and rainfed conditions, with the highest accumulation observed under irrigated conditions (33.59 g/plant) and the lowest under rainfed conditions (26.99 g/plant). Genotype SPV-486 exhibited the highest leaf dry matter accumulation (36.90 g/plant), while Tandur L had the lowest (22.37 g/plant). The limited availability of water affects leaf dry weight by reducing leaf area, thickness, and cell expansion, ultimately leading to a decrease in their dry weight (Pawar and Gadakh, 2018). However, M-35-1 displayed the highest stem dry weight (126.71 g/plant), while Tandur L had the lowest (74.42 g/plant). Similarly, previous findings by Saberi and Aishah (2013) indicate that drought stress affects stem dry weight by influencing cell elongation and division, leading to reduced stem growth and biomass accumulation. Insufficient water availability limits the production of structural materials necessary for stem development, resulting in a decline in stem dry weight.

Panicle dry matter exhibited a significant difference between rainfed and irrigated conditions. BJV-44 recorded the highest panicle weight (106.08 g/plant) under non-stress conditions, while under stress, BJV-44 and Phule Anuradha maintained relatively high panicle weights (111.3 and 110.77 g/plant, respectively). Whereas, Phule Anuradha exhibited the highest total dry matter (261.04 g/plant), followed by BJV-4 (250.14 g/plant) and M-35-1 (246.65 g/plant), while Tandur L had the lowest (154.11 g/plant). Conversely, M 148-138 experienced a significant reduction in total dry matter under rainfed conditions compared to irrigated conditions.

3.2 Grain Yield per Plant:

Significant variations were observed in yield parameters concerning irrigation, genotypes, and their interactions (Table 3). Irrigated conditions yielded a substantially higher mean grain yield of 70.23 g/plant, while rainfed conditions resulted in a significantly lower mean grain yield of 54.54 g/plant. Among the genotypes, BJV-44 exhibited the highest grain yield at 78.13 g/plant. Conversely, SVD-1272R (43.66 g/plant) and Chitapur - L (48.59 g/plant) recorded notably lower mean seed yields per plant. Genotypes M 148-138 and Tandur L displayed the most significant reduction in grain yield per plant under rainfed conditions, with reductions of 34.3 grams and 30.9 grams, respectively, compared to irrigated conditions. These findings suggest that M 148-138 and Tandur L were vulnerable to induced water stress, leading to significant yield reduction. Abderhim *et al*. (2017) have previously highlighted how water scarcity can impact stomatal conductance, leading to reduced carbon dioxide uptake for photosynthesis, ultimately limiting assimilate production crucial for grain filling and yield formation.

Table 2 : Effect of drought stress on dry matter distribution in sorghum genotypes (Pooled 2021-22 and 2022-23)

Genotypes		Leaf dry weight (g)			Stem dry weight (g)			Panicle dry weight (g)			Total dry weight (g)		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	30.27	23.82	27.04	95.41	79.68	87.54	58.70	50.35	54.52	184.37	153.84	169.11
2	SVD-1358R	32.64	26.06	29.35	103.38	88.88	96.13	81.34	68.44	74.89	217.36	183.38	200.37
3	SVD-1528R	33.49	22.36	27.92	102.67	86.78	94.73	77.31	58.09	67.70	213.46	167.22	190.34
4	SVD-1403R	34.79	28.40	31.59	95.51	83.61	89.56	79.57	65.73	72.65	209.87	177.73	193.80
5	SPV-486	39.11	34.70	36.90	103.58	91.78	97.68	97.66	86.74	92.20	240.34	213.21	226.78
6	SPV-2217	37.29	28.55	32.92	108.75	97.12	102.94	85.12	67.68	76.40	231.15	193.35	212.25
7	CSV-216R	32.41	25.55	28.98	101.22	89.95	95.58	69.56	59.14	64.35	203.18	174.63	188.91
8	CSV-29R	34.92	29.78	32.35	110.34	100.24	105.29	89.50	78.29	83.90	234.75	208.31	221.53
9	ICSR-15001	29.00	22.09	25.54	85.84	70.57	78.20	73.43	50.79	62.11	188.26	143.44	165.85
10	Basavana pada	33.34	26.40	29.87	85.85	69.75	77.80	84.50	70.48	77.49	203.69	166.63	185.16
11	Tandur L	27.29	17.44	22.37	84.57	64.27	74.42	84.29	50.37	67.33	196.14	132.08	164.11
12	Phule Anuradha	36.83	30.28	33.55	125.03	119.94	122.48	120.77	109.25	115.01	282.62	259.46	271.04
13	Chitapur – L	28.89	20.37	24.63	108.58	87.84	98.21	66.28	42.55	54.42	203.74	150.75	177.25
14	DKS- 35	37.14	32.18	34.66	126.67	109.49	118.08	108.40	94.18	101.29	272.21	235.85	254.03
15	M-35-1	39.20	33.52	36.36	129.29	124.14	126.71	95.91	91.26	93.58	264.39	248.91	256.65
16	M 148-138	29.86	21.89	25.87	123.43	102.81	113.12	96.42	58.74	77.58	249.71	183.43	216.57
17	Basavan moti	35.75	30.41	33.08	110.62	106.79	108.70	87.13	76.44	81.78	233.50	213.63	223.56
18	Phule Vasudha	33.68	31.13	32.40	116.37	105.92	111.15	89.38	78.98	84.18	239.43	216.03	227.73
19	BJV-44	38.22	34.26	36.24	108.44	102.15	105.30	121.13	116.08	118.60	267.78	252.48	260.13
20	ICSR- 13025	27.80	20.62	24.21	95.10	83.94	89.52	84.71	62.52	73.62	207.61	167.08	187.35
Mean		33.59	26.99	30.29	106.03	93.28	99.66	87.55	71.81	79.68	227.18	192.07	209.63

	S.Em. ±	CD @5%	S.Em. ±	CD @5%	S.Em. ±	CD @5%	S.Em. ±	CD @5%
Main plot (M)	4.097	13.064	28.690	64.541	8.020	31.904	24.768	68.701
Sub Plot (P)	2.706	8.385	11.774	39.604	7.053	27.611	14.967	50.178
Interaction	8.341	23.880	36.290	103.896	21.737	62.232	46.133	132.074

3.3 Grain Yield per Hectare:

Grain yield was significantly influenced by water stress conditions. Under irrigated conditions, grain yield ranged from 493.11 to 1539.14 kg/ha, with an average yield of 1143 kg/ha. In contrast, under rainfed condition, grain yield ranged from 316.07 to 1362.16 kg/ha, with an average yield of 1002 kg/ha. Among the genotypes, DKS-35 exhibited the highest average grain yield at 1444 kg/ha. while, Chitapur – L and Tandur L recorded significantly lower grain yields at 405 kg/ha and 656 kg/ha, respectively. These reductions in yield under moisture stress conditions are in line with findings reported by Narkhede *et al*. (2011) and Baturaygil *et al*. (2021) in sorghum. Limited water availability disrupts the plant's ability to maintain proper turgor pressure, leading to reduced cell expansion and affecting essential morphological traits such as leaf area, plant height, and chlorophyll production, ultimately constraining potential grain yield.

3.4 Stover Yield:

Moisture stress significantly affects the stover yield of sorghum genotypes. Limited water availability during critical growth stages negatively impacts plant growth and development, resulting in a decrease in stover yield (Indu *et al*., 2021). Stover yield was notably higher under irrigated conditions, reaching 5413 kg/ha, whereas rainfed conditions resulted in a significant reduction, with an average of 3761 kg/ha. Among the genotypes, M-35-1 exhibited the highest mean stover yield at 5627 kg/ha. Additionally, the genotype SVD-1272R showed a decrease of approximately 1685 kg/ha in stover yield under stress conditions compared to non-stress conditions. As highlighted by Shinde *et al*. (2017), water stress leads to a decrease in assimilate production. Consequently, there is limited availability of carbohydrates for biomass accumulation in above-ground plant parts such as stems, leaves, and panicles, ultimately resulting in a reduction in stover yield.

3.5 Harvest Index:

The harvest index is the proportion of the total dry weight allocated to the harvested portion, typically the grain. Souza *et al*. (2021) observed that under drought conditions, limited water availability affects various physiological processes in sorghum plants, resulting in changes in resource allocation and a decrease in the harvest index. The irrigated condition displayed a significantly higher mean harvest index of 30.91%, while the rainfed condition had a lower mean harvest index of 28.13%. Under non-stress conditions, Basavana pada had the highest harvest index at 36.23%, followed by Tandur L (36.19%). In the stress regime, Basavana pada (34.27%) and Phule Vasudha (31.83%) had the highest harvest indices. Drought stress, as per Fisher and Maurer (2018), reduces chlorophyll content and leaf area, hindering vital carbohydrate availability for grain filling. Overall, drought stress lowers sorghum harvest index via reduced above-ground biomass and impaired grain assimilate allocation.

3.6 Drought Tolerance Measurement Indices:

Susceptibility Index: Drought susceptibility index (DSI) provides valuable information about how various genotypes perform under conditions of limited water availability compared to normal conditions (Yahaya *et al.*, 2023). DSI values ranged from 0.30 to 2.90, with an average of 1.10. Basavan moti exhibited the lowest DSI of 0.30, indicating higher resistance to drought stress (Table 4). In contrast, Chitapur – L displayed the highest DSI of 2.90, indicating greater susceptibility to drought stress.

3.7 Stress Tolerance Index: It is a measurement used to assess the resilience of plant genotypes to drought stress (Menezes *et al.*, 2014). Genotypes with higher STI values are considered more tolerant to drought. In this study, DKS-35 had the highest STI of 1.59, followed by Phule Vasudha (1.49) and M-35-1 (1.31), indicating their greater ability to tolerate and recover from drought stress

3.8 Yield Stability Ratio (YS): The Yield Stability Ratio provides valuable information about how genotypes maintain relatively higher yields even under challenging water-deficit conditions (Ongom *et al.*, 2016). A higher YS ratio indicates greater stability of a genotype under drought stress. Yield stability ratio ranged from 64.11 to 96.34, with an average of 86.41 (Table 4). Basavan moti exhibited the highest YS ratio of 96.34, indicating superior consistency in maintaining high yields across different drought events or varying water availability.

Table 3: Effect of drought stress on stover yield, Grain yield/plant, grain yield/ha and harvest index in sorghum genotypes (Pooled 2021-22 and 2022-23)

	Genotypes	Grain yield (kg/ha)			Grain yield/plant (g)			Stover Yield (kg/ha)			Harvest Index (%)		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	952	852	**902**	51.18	36.15	**43.66**	5007	3186	**4096**	27.76	23.48	**25.62**
2	SVD-1358R	1169	1037	**1103**	68.02	55.54	**61.78**	5110	3457	**4284**	31.32	30.32	**30.82**
3	SVD-1528R	1012	828	**920**	65.03	44.51	**54.77**	5234	3525	**4380**	30.44	26.60	**28.52**
4	SVD-1403R	1444	1123	**1283**	69.49	55.73	**62.61**	5342	3601	**4471**	32.34	30.58	**31.46**
5	SPV-486	1260	1171	**1215**	75.74	62.42	**69.08**	4975	3321	**4148**	31.53	29.24	**30.38**
6	SPV-2217	1129	982	**1055**	68.56	52.90	**60.73**	5880	4091	**4985**	29.70	27.38	**28.54**
7	CSV-216R	890	812	**851**	56.77	46.71	**51.74**	5306	3569	**4437**	27.93	26.76	**27.35**
8	CSV-29R	1163	1075	**1119**	73.05	62.65	**67.85**	5728	4051	**4890**	31.12	30.10	**30.61**
9	ICSR-15001	872	619	**745**	59.01	39.29	**49.15**	4512	2907	**3710**	31.30	27.33	**29.32**
10	Basavana pada	1302	1207	**1255**	76.03	59.18	**67.61**	4656	3042	**3849**	36.23	34.27	**35.25**
11	Tandur L	738	573	**656**	70.96	40.04	**55.50**	4544	2803	**3674**	36.19	30.32	**33.26**
12	Phule Anuradha	1156	1063	**1109**	80.58	70.36	**75.47**	6235	4701	**5468**	28.23	26.97	**27.60**
13	Chitapur – L	493	316	**405**	61.90	35.28	**48.59**	4777	3027	**3902**	30.35	23.00	**26.67**
14	DKS- 35	1539	1348	**1444**	80.82	70.86	**75.84**	6075	4422	**5249**	28.41	28.29	**28.35**
15	M-35-1	1350	1271	**1310**	79.88	73.50	**76.69**	6394	4860	**5627**	30.21	29.54	**29.88**
16	M 148-138	1350	1095	**1222**	78.67	44.36	**61.51**	5517	3824	**4671**	31.51	24.18	**27.85**
17	Basavan moti	1306	1258	**1282**	63.69	52.73	**58.21**	5900	4461	**5180**	28.49	25.90	**27.20**
18	Phule Vasudha	1426	1362	**1394**	75.52	68.73	**72.12**	5983	4454	**5219**	31.57	31.83	**31.70**
19	BJV-44	1332	1269	**1300**	80.08	76.17	**78.13**	6115	4621	**5368**	30.00	30.25	**30.12**
20	ICSR- 13025	983	780	**882**	69.52	43.75	**56.64**	4975	3289	**4132**	33.49	26.18	**29.84**
	Mean	**1143**	**1002**	**1073**	**70.23**	**54.54**	**62.38**	**5413**	**3761**	**4587**	**30.91**	**28.13**	**29.52**
		S.Em. ±		**CD @5%**	**S.Em. ±**		**CD @5%**	**S.Em. ±**		**CD @5%**	**S.Em. ±**		**CD @5%**
	Main plot (M)	265.635		775.212	13.520		51.788	547.603		1757.958	5.020		14.784
	Sub Plot (P)	111.026		410.725	4.982		13.297	229.772		619.526	2.836		7.037
	Interaction	342.207		979.712	15.354		43.958	708.204		2027.535	8.742		25.027

Table 4: Estimates of drought tolerance measurement indices for 20 genotypes in sorghum (Pooled 2021-22 and 2022-23)

Genotypes		Drought Susceptibility Index (DSI)	Stress Tolerance Index (STI)	Yield stability ratio (YS)
1	SVD-1272R	0.85	0.62	89.54
2	SVD-1358R	0.91	0.93	88.76
3	SVD-1528R	1.47	0.64	81.89
4	SVD-1403R	1.80	1.24	77.79
5	SPV-486	0.58	1.13	92.89
6	SPV-2217	1.06	0.85	86.95
7	CSV-216R	0.71	0.55	91.28
8	CSV-29R	0.61	0.96	92.47
9	ICSR-15001	2.35	0.41	71.00
10	Basavana pada	0.59	1.20	92.66
11	Tandur L	1.81	0.32	77.63
12	Phule Anuradha	0.65	0.94	91.91
13	Chitapur - L	2.90	0.12	64.11
14	DKS- 35	1.01	1.59	87.58
15	M-35-1	0.48	1.31	94.10
16	M 148-138	1.53	1.13	81.12
17	Basavan moti	0.30	1.26	96.34
18	Phule Vasudha	0.36	1.49	95.53
19	BJV-44	0.39	1.29	95.22
20	ICSR- 13025	1.67	0.59	79.35

4. CONCLUSION

This study investigated the effects of moisture stress on sorghum growth, yield parameters, and drought tolerance indices. Moisture stress significantly impacted sorghum in various aspects, reducing leaf and stem dry matter accumulation, grain yield per plant and per hectare, stover yield, and the harvest index. However, certain genotypes, like BJV-44 and M-35-1, demonstrated resilience by maintaining relatively higher grain yields under rainfed conditions. These findings emphasize the importance of selecting drought-tolerant sorghum genotypes for sustainable cultivation in regions prone to water shortages. Such choices are crucial for ensuring food security and building agricultural resilience in the face of changing climate patterns.

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