



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

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Authors' contributions

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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,

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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.

Keywords: 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 [1]. 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 [2]. 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

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

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 [3].

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 [4].

$$HI (\%) = (\text{Economic yield} / \text{Biological yield}) \times 100.$$

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 $1 - (Y_s/Y_p) / D$, where Y_s represents yield under moisture stress, Y_p 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 $(\bar{Y}_p \times Y_s) / (\bar{Y}_p)^2$, with Y_p representing potential yield under irrigated conditions, Y_s as potential yield under rainfed conditions, and Y_p as the mean yield of all genotypes under irrigated conditions [5].

2.4.8 Yield stability ratio (YS)

Determined as (Grain yield under stress / Grain yield under control) x 100, according to Lewis [6].

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 [7]. 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 [8] 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. [9] 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.

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. [10] and Baturaygil et al. [11] 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 [12]. 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. [13], 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.

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	

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

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. [14] 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 [15], 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.

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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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