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Navyashree R
Department of Crop Physiology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka, India

Mummigatti UV
Department of Crop Physiology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka, India

Nethra P
Department of Crop Physiology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka, India

Basavaraj B
Department of Molecular Biology and Biotechnology, University of Agricultural Sciences, Dharwad, Karnataka, India

Hanamaratti NG
AICRP on Sorghum, MARS, University of Agricultural Sciences, Dharwad, Karnataka, India

Corresponding Author:
Navyashree R
Department of Crop Physiology, College of Agriculture, University of Agricultural Sciences, Dharwad, India

Effect of drought stress on physiological parameters in sorghum: Adaptive changes and correlations with yield under water stress conditions

Navyashree R, Mummigatti UV, Nethra P, Basavaraj B and Hanamaratti NG

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Abstract

Sorghum (*Sorghum bicolor* L. Moench) is a crucial cereal crop in India, grown in both kharif and rabi seasons. Adequate soil moisture is essential for optimal yield, particularly in arid regions where drought and abiotic stresses can severely impact crop performance. This study aimed to identify drought-tolerant sorghum genotypes by evaluating their physiological responses under varying moisture conditions. Conducted over two rabi seasons (2021-22 and 2022-23), the experiment used a split-plot design with two replications, evaluating twenty sorghum genotypes under rainfed and irrigated conditions. Key physiological parameters, including chlorophyll content and relative water content (RWC), were assessed. Results indicated significant variability among genotypes in terms of adaptability to water stress. The Chitapur-L genotype showed a 14% and 18% decrease in total chlorophyll content at 60 and 90 days after sowing, respectively, under rainfed conditions. The ICSR-15001 genotype had the lowest mean RWC at 90 days, reflecting poor water retention. In contrast, Basavan moti demonstrated minimal RWC reduction (4.5%) under rainfed conditions, highlighting its superior water retention capability. Tandur L exhibited a significant 17% reduction in leaf RWC at 90 days under rainfed conditions. These findings offer insights into the morpho-physiological traits of sorghum genotypes, facilitating the selection of drought-resistant varieties. M-35-1, BJV 44, Basavan moti, DKS-35, and Phule Anuradha emerged as drought-tolerant genotypes, while M-148-138 and Chitapur L were identified as susceptible to moisture stress.

Keywords: Sorghum, drought tolerance, physiological parameters, relative water content (RWC), chlorophyll content and rainfed conditions

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a vital cereal crop in India, cultivated in both the kharif (rainy) and rabi (post-rainy) seasons. The rabi produce is predominantly utilized for human consumption, whereas the kharif produce is mainly directed towards animal feed, starch, and alcohol industries. Despite its importance, only 5% of India's sorghum area is irrigated, with over 48% of the cultivation concentrated in the states of Maharashtra and Karnataka. Rabi sorghum, grown primarily under rainfed conditions in the semi-arid Deccan Plateau, encompassing Maharashtra, Karnataka, and Andhra Pradesh, is the most significant post-rainy cereal crop in Peninsular India. However, productivity in these regions is often hampered by limited and erratic rainfall, leading to moisture stress during critical growth stages and significant yield losses (Kumar *et al*., 2022) [11].

Adequate soil moisture is crucial for successful crop production in arid regions, as drought and other abiotic stresses adversely affect yield and plant growth by restricting photosynthesis and limiting the availability of photosynthetic assimilates and energy. Plants have developed various adaptive mechanisms to cope with water stress, including drought escape, dehydration avoidance, and dehydration tolerance. These mechanisms result from a combination of morphoanatomical, physiological, biochemical, and molecular changes (Rakshit *et al*., 2012) [14]. Drought impacts essential physiological and biochemical processes in plants, such as chlorophyll destruction, enzymatic activities, and protein synthesis. Addressing the challenge of minimizing crop yield losses in drought-prone areas requires a focus on genetic improvement for drought tolerance. Key strategies involve drought escape, drought avoidance, or enhancing drought tolerance. Characterizing stress-tolerant genotypes in sorghum involves evaluating root growth, leaf area development, epicuticular wax synthesis, and osmotic adaptation under stress conditions (Sanchez *et al*., 2011) [16]. The primary objective of this study is to identify drought-tolerant sorghum genotypes based on these physiological parameters.

Materials and Methods

Design and layout

During the rabi seasons of 2021-22 and 2022-23, an experiment was conducted using a split-plot design with two replications. Twenty sorghum genotypes (listed in Table 1) were field-grown under two different moisture conditions. The aim was to characterize their Physiological and yield-determining features.

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

Observations recorded

SPAD reading

The relative chlorophyll content was measured using the Konica Minolta SPAD-502Plus chlorophyll meter, which detects light attenuation at 430 nm (chlorophyll a and b peak) and near-infrared at 750 nm (no transmittance). The SPAD Chlorophyll Meter Reading (SCMR) provides a unitless value indicating the relative leaf chlorophyll amount. Measurements were taken at three locations on each tagged plant, averaging three points on a single leaf per observation, and the average SPAD value was recorded.

Relative water content in leaves

Leaf hydration status, relative to its maximal water holding capacity at full turgidity as per Barrs and Weatherly (1962) [5], was measured. Leaf punches were taken from the third leaf of each genotype, weighed fresh, and then floated in water for 4 hours to gain turgidity. After recording the turgid weights, the samples were dried in a hot air oven at 80 °C to a constant weight to obtain the dry weight. Relative Water Content (RWC) was then estimated and expressed as a percentage using the following formula.

$$\text{Relative water content (\%)} = \frac{\text{Fresh Weight} - \text{Dry Weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Chlorophyll content in leaf

Aqueous solutions of DMSO make the plasmalemma permeable, allowing chlorophyll pigments to dissolve. Chlorophyll content in plant tissue was estimated by measuring the optical density (OD) at 664.9 nm and 648.2 nm, using Barnes *et al*.'s (1992) [4] formulae. Fresh leaf tissue (100 mg) was cut into pieces and incubated in 20 ml of DMSO in the dark for 24 hours. The OD was measured with a UV-VIS spectrophotometer, ensuring the volume remained at 20 ml with a 10 mm path length cuvette. Chlorophyll a, chlorophyll b, the chlorophyll a/b ratio, and total chlorophyll content were calculated and expressed in micrograms per gram fresh weight (µg g^{-1} FW).

Chlorophyll a (µg/ml) = [(14.85 x $A_{664.9}$) - (5.14 x $A_{648.2}$)]
Chlorophyll b (µg/ml) = [(25.48 x $A_{648.2}$) - (7.36 x $A_{664.9}$)]
Total chlorophyll (µg/ml) = [(7.49 x $A_{664.9}$) + (20.34 x $A_{648.2}$)]

where, A is the absorbance at given wavelength

Membrane stability index (%)

To assess membrane stability index, two sets of 200 mg samples were placed in test tubes, each containing 10 ml of double-distilled water. One set was exposed to 40 °C for 30 minutes in a water bath, and the electrical conductivity of the solution was measured using a conductivity meter (C1). The second set was boiled at 100 °C for 10 minutes, and the resulting conductivity (C2) was measured. The membrane stability index was calculated using the methodology of Kamatar and Nayakar (2004) [9] and expressed as a percentage.

MSI (%) = [1- {C1/C2}] ×100

Grain Yield per Plant (g): The panicle heads were threshed, and the average grain weight per head was measured and expressed in grams.

Correlation Plot Analysis

A correlation plot was created using R software. The dataset was imported and a correlation matrix was computed with the cor() function. The correlation plot was generated using the corrplot() function from the corrplot package.

Results

SPAD chlorophyll meter reading

SPAD values measured at 30, 60, and 90 days after sowing varied significantly across genotypes and moisture conditions (Table 2). At 60 days, irrigated conditions had higher mean SPAD values (44.09) than rainfed conditions (40.56). At 90 days, Phule Anuradha (40.66) and M-35-1 (39.35) had the highest SPAD values, followed by BJV-44 (39.26), Basavan Moti (38.40), and DKS-35 (35.16). During the first 30 days, SPV-486 (34.23) and M-35-1 (34.98) had the highest SPAD values under irrigation. After 50% flowering, SPAD values increased, but Chitapur-L had the lowest SPAD value (34.80) under moisture stress at 60 days, followed by M-35-1 (46.20), DKS-35 (45.80), BJV-44 (45.50), and SPV-486 (44.80). The mean SPAD value at 60 days was 12% lower under rainfed conditions compared to irrigated conditions, with Chitapur-L and M-148-138 showing reductions of 26% and 28%, respectively, under rainfed conditions.

Leaf chlorophyll content

Chlorophyll content was analyzed using dimethyl sulfoxide (DMSO), measuring chlorophyll a, b, and total chlorophyll at specific wavelengths. Chlorophyll a (Table 3) was consistently higher than chlorophyll b (Table 4), with an average of 1.591 mg g^{-1} under water stress at 60 days after sowing, about 10% lower than non-stress conditions. Chlorophyll b also showed a similar pattern, with the highest mean content at 90 days in irrigated conditions (0.788 mg g^{-1}), compared to rainfed conditions (0.705 mg g^{-1}). M-35-1 had the highest chlorophyll a concentration at 60 days (1.925 mg g^{-1}), while DKS-35 had the highest at 90 days (1.654 mg g^{-1}). The total chlorophyll content (Table 5) was highest for M-35-1 at 60 days (2.962 mg g^{-1}), followed by DKS-35 (2.926 mg g^{-1}), SPV-486 (2.840 mg g^{-1}), and BJV-44 (2.799 mg g^{-1}). At 90 days, DKS-35 had the highest total chlorophyll (2.518 mg g^{-1}) and Chitapur-L had the lowest (1.946 mg g^{-1}). Under rainfed conditions, Chitapur-L showed a 14% decrease in total chlorophyll content at 60 days (from 2.254 to 1.932 mg g^{-1}) and an 18% decrease at 90 days (from 2.138 to 1.754 mg g^{-1}) compared to irrigated conditions.

Relative water content

Sorghum genotypes were assessed for adaptability to soil moisture by measuring leaf relative water content (RWC) at various stages (Table 6). At 30 days after sowing, there was no significant difference in RWC between stress and non-stress conditions. However, differences became evident at 60 and 90 days. The maximum mean RWC was observed under irrigated conditions at 60 and 90 days after sowing (83.80% and 75.58%, respectively), compared to the lower RWC in rainfed conditions (79.02% and 69.32%). Among genotypes, Phule Vasudha had the highest mean RWC (90.41%) at 30 days, while ICSR-15001 had the lowest (79.85%). At 60 and 90 days, BJV-44 (84.52%) and M-35-1 (77.59%) showed the highest RWC, respectively, with ICSR-15001 having the lowest RWC at 90 days (64.49%). Under rainfed conditions, Basavan Moti showed minimal reduction in RWC (77.94% in irrigated and 74.46% in rainfed), while Tandur L experienced a significant reduction (73.32% in irrigated and 60.84% in rainfed) at 90 days after sowing.

Membrane stability index

Data on Membrane Stability Index (MSI) at 30, 60, and 90 days after sowing showed significant variations among genotypes and moisture stress levels (Table 7). At 60 days, irrigated conditions had a higher average MSI (81.15%) compared to rainfed conditions (76.43%). Phule Anuradha and DKS-35 had the highest MSI values at 60 days (85.7% and 85.09%, respectively), followed by ICSR-13025, Phule Vasudha, and CSV-29R (83.82%, 83.15%, and 82.7%, respectively). SVD-1272R and SPV-2217 had the lowest MSI values (70.64% and 71.33%, respectively). Under both conditions, Phule Anuradha had the highest MSI values (82.17% irrigated and 69.27% rainfed). SPV-486 showed the least reduction in MSI under rainfed conditions (75.26% irrigated and 63.78% rainfed), while Tandur L experienced the greatest reduction (69.97% irrigated and 55.76% rainfed) at 90 days.

Table 2: Effect of drought stress on SPAD values at 30, 60 and 90 DAS in sorghum genotypes (Pooled 2021-22 and 2022-23)

Genotypes		SPAD values								
		30DAS			60DAS			90DAS		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	25.90	24.87	25.38	42.32	37.50	39.91	31.96	27.27	29.61
2	SVD-1358R	24.80	23.44	24.12	44.40	39.02	41.71	33.66	29.75	31.71
3	SVD-1528R	24.02	24.60	24.31	41.82	36.90	39.36	31.26	25.76	28.51
4	SVD-1403R	28.10	26.30	27.20	46.30	41.68	43.99	35.95	29.26	32.60
5	SPV-486	34.23	30.18	32.20	47.88	44.80	46.34	33.26	30.67	31.96
6	SPV-2217	26.42	25.70	26.06	46.80	41.29	44.04	34.67	30.24	32.46
7	CSV-216R	24.48	22.72	23.60	40.90	38.82	39.86	31.16	27.24	29.20
8	CSV-29R	32.52	30.18	31.35	44.60	43.22	43.91	35.17	31.76	33.46
9	ICSR-15001	32.05	26.87	29.46	42.42	35.69	39.05	34.56	28.74	31.65
10	Basavana pada	25.30	24.30	24.80	43.92	40.90	42.41	35.67	31.66	33.66
11	Tandur L	27.80	25.92	26.86	40.50	35.20	37.85	32.76	27.15	29.95
12	Phule Anuradha	33.70	30.37	32.03	44.70	43.70	44.20	42.07	39.26	40.66
13	Chitapur - L	25.10	23.54	24.32	41.39	34.80	38.09	34.15	25.27	29.71
14	DKS- 35	34.22	31.90	33.06	47.72	45.80	46.76	36.56	33.77	35.16
15	M-35-1	34.98	30.52	32.75	48.10	46.20	47.15	41.16	37.54	39.35
16	M 148-138	30.64	26.52	28.58	40.10	36.00	38.05	29.27	26.82	28.05
17	Basavan moti	28.40	27.70	28.05	43.62	42.40	43.01	39.16	37.65	38.40
18	Phule Vasudha	25.52	25.20	25.36	46.12	43.60	44.86	34.86	31.96	33.41
19	BJV-44	31.00	28.00	29.50	47.20	45.50	46.35	40.67	37.86	39.26
20	ICSR- 13025	26.20	25.90	26.05	41.00	38.12	39.56	33.05	29.46	31.25
Mean		28.77	26.74	27.75	44.09	40.56	42.32	35.05	30.95	33.00

	S.Em. ±	CD @ 5%	S.Em. ±	CD @ 5%	S.Em. ±	CD @ 5%
Main plot (M)	12.703	39.401	0.017	0.042	1.605	5.393
Sub Plot (P)	0.748	5.500	0.913	2.595	0.732	3.302
Interaction	2.304	6.597	2.813	8.052	2.256	6.460

Table 3: Effect of drought stress on leaf chlorophyll "*a*" content (mg g^{-1}fr. wt.) at 30, 60 and 90 DAS in sorghum genotypes (Pooled 2021-22 and 2022-23)

Genotypes		Chlorophyll "*a*" content								
		30DAS			60DAS			90DAS		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	1.134	1.136	1.135	1.612	1.483	1.547	1.391	1.283	1.337
2	SVD-1358R	1.009	1.008	1.008	1.775	1.501	1.638	1.434	1.380	1.407
3	SVD-1528R	1.055	1.058	1.056	1.691	1.422	1.557	1.354	1.230	1.292
4	SVD-1403R	1.241	1.242	1.242	1.822	1.659	1.741	1.524	1.336	1.430
5	SPV-486	1.449	1.449	1.449	2.002	1.805	1.904	1.683	1.566	1.624
6	SPV-2217	1.173	1.174	1.174	1.855	1.640	1.748	1.518	1.365	1.441
7	CSV-216R	0.934	0.920	0.927	1.662	1.493	1.578	1.459	1.303	1.381
8	CSV-29R	1.362	1.340	1.351	1.768	1.724	1.746	1.469	1.435	1.452
9	ICSR-15001	1.396	1.234	1.315	1.695	1.377	1.536	1.512	1.289	1.401
10	Basavana pada	1.170	1.004	1.087	1.786	1.630	1.708	1.458	1.398	1.428
11	Tandur L	1.262	1.150	1.206	1.504	1.262	1.383	1.430	1.281	1.356
12	Phule Anuradha	1.418	1.410	1.414	1.785	1.716	1.751	1.595	1.509	1.552
13	Chitapur - L	1.095	0.965	1.030	1.490	1.247	1.369	1.411	1.186	1.298
14	DKS- 35	1.427	1.435	1.431	1.999	1.901	1.950	1.712	1.654	1.683
15	M-35-1	1.481	1.422	1.452	2.014	1.925	1.970	1.656	1.572	1.614
16	M 148-138	1.352	1.173	1.262	1.622	1.389	1.506	1.426	1.201	1.313
17	Basavan moti	1.320	1.285	1.303	1.764	1.681	1.723	1.533	1.488	1.510
18	Phule Vasudha	1.205	1.076	1.141	1.807	1.681	1.744	1.466	1.452	1.459
19	BJV-44	1.355	1.300	1.328	1.902	1.821	1.862	1.641	1.608	1.624
20	ICSR- 13025	1.231	1.130	1.181	1.632	1.454	1.543	1.432	1.333	1.383
Mean		1.254	1.196	1.225	1.759	1.591	1.675	1.505	1.393	1.449
		S.Em. ±		CD @ 5%	S.Em. ±		CD @ 5%	S.Em. ±		CD @ 5%
Main plot (M)		0.458		2.816	0.004		0.024	0.002		0.005
Sub Plot (P)		0.076		0.466	0.032		0.107	0.027		0.086
Interaction		0.234		0.671	0.099		0.283	0.083		0.238

Table 4: Effect of drought stress on leaf chlorophyll "*b*" content (mg g^{-1}fr. wt.) at 30, 60 and 90 DAS in sorghum genotypes (Pooled 2021-22 and 2022-23)

Genotypes		Chlorophyll "*b*" content								
		30DAS			60DAS			90DAS		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	0.431	0.395	0.413	0.796	0.730	0.763	0.694	0.646	0.670
2	SVD-1358R	0.323	0.355	0.339	0.851	0.791	0.821	0.763	0.665	0.714
3	SVD-1528R	0.381	0.344	0.363	0.809	0.744	0.777	0.749	0.643	0.696
4	SVD-1403R	0.444	0.478	0.461	0.890	0.826	0.858	0.796	0.686	0.741
5	SPV-486	0.605	0.629	0.617	0.966	0.906	0.936	0.901	0.799	0.850
6	SPV-2217	0.404	0.465	0.435	0.890	0.820	0.855	0.789	0.681	0.735
7	CSV-216R	0.336	0.288	0.312	0.814	0.751	0.783	0.759	0.663	0.711
8	CSV-29R	0.573	0.492	0.533	0.889	0.841	0.865	0.836	0.749	0.793
9	ICSR-15001	0.564	0.463	0.514	0.773	0.706	0.740	0.743	0.619	0.681
10	Basavana pada	0.414	0.369	0.392	0.865	0.807	0.836	0.771	0.715	0.743
11	Tandur L	0.471	0.425	0.448	0.755	0.664	0.710	0.744	0.589	0.667
12	Phule Anuradha	0.579	0.511	0.545	0.915	0.871	0.893	0.859	0.796	0.828
13	Chitapur - L	0.385	0.360	0.373	0.764	0.685	0.725	0.727	0.568	0.648
14	DKS- 35	0.587	0.593	0.590	0.998	0.953	0.976	0.863	0.808	0.836
15	M-35-1	0.634	0.565	0.600	0.990	0.969	0.980	0.840	0.798	0.819
16	M 148-138	0.559	0.479	0.519	0.787	0.720	0.754	0.696	0.625	0.661
17	Basavan moti	0.497	0.484	0.491	0.907	0.888	0.898	0.804	0.765	0.785
18	Phule Vasudha	0.420	0.400	0.410	0.879	0.825	0.852	0.755	0.724	0.740
19	BJV-44	0.511	0.491	0.501	0.949	0.926	0.938	0.908	0.852	0.880
20	ICSR- 13025	0.446	0.417	0.432	0.779	0.733	0.756	0.757	0.700	0.729
Mean		0.478	0.450	0.464	0.863	0.808	0.836	0.788	0.705	0.746
		S.Em. ±		CD @ 5%	S.Em. ±		CD @ 5%	S.Em. ±		CD @ 5%
Main plot (M)		0.000		0.003	0.002		0.008	0.001		0.003
Sub Plot (P)		0.015		0.058	0.018		0.057	0.016		0.054
Interaction		0.046		0.131	0.055		0.158	0.050		0.142

Table 5: Effect of drought stress on total leaf chlorophyll content (mg g^{-1}fr. wt.) at 30, 60 and 90 DAS in sorghum genotypes (Pooled 2021-22 and 2022-23)

Genotypes		Total leaf chlorophyll content								
		30DAS			60DAS			90DAS		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	1.565	1.531	1.548	2.408	2.213	2.310	2.085	1.929	2.007
2	SVD-1358R	1.332	1.363	1.347	2.626	2.292	2.459	2.197	2.045	2.121
3	SVD-1528R	1.436	1.402	1.419	2.500	2.166	2.333	2.103	1.873	1.988
4	SVD-1403R	1.685	1.670	1.678	2.712	2.486	2.599	2.320	2.022	2.171
5	SPV-486	2.054	2.003	2.029	2.968	2.711	2.840	2.584	2.365	2.474
6	SPV-2217	1.577	1.639	1.608	2.745	2.460	2.603	2.307	2.046	2.176
7	CSV-216R	1.270	1.208	1.239	2.476	2.244	2.360	2.218	1.966	2.092
8	CSV-29R	1.885	1.773	1.829	2.657	2.565	2.611	2.305	2.184	2.244
9	ICSR-15001	1.890	1.598	1.744	2.468	2.083	2.276	2.255	1.909	2.082
10	Basavana pada	1.584	1.373	1.479	2.651	2.437	2.544	2.229	2.113	2.171
11	Tandur L	1.733	1.525	1.629	2.259	1.926	2.093	2.174	1.870	2.022
12	Phule Anuradha	1.947	1.857	1.902	2.700	2.587	2.644	2.454	2.305	2.379
13	Chitapur - L	1.480	1.325	1.403	2.254	1.932	2.093	2.138	1.754	1.946
14	DKS- 35	2.014	2.028	2.021	2.997	2.854	2.926	2.575	2.462	2.518
15	M-35-1	2.111	1.976	2.043	3.029	2.894	2.962	2.496	2.370	2.433
16	M 148-138	1.811	1.502	1.656	2.409	2.109	2.259	2.122	1.826	1.974
17	Basavan moti	1.817	1.747	1.782	2.671	2.569	2.620	2.337	2.253	2.295
18	Phule Vasudha	1.625	1.476	1.551	2.686	2.506	2.596	2.221	2.176	2.198
19	BJV-44	1.866	1.791	1.829	2.851	2.747	2.799	2.549	2.460	2.504
20	ICSR- 13025	1.677	1.547	1.612	2.411	2.187	2.299	2.189	2.033	2.111
Mean		1.718	1.617	1.667	2.624	2.398	2.511	2.293	2.098	2.195

	S.Em. ±	CD @ 5%	S.Em. ±	CD @ 5%	S.Em. ±	CD @ 5%
Main plot (M)	0.765	4.717	0.022	0.086	0.003	0.008
Sub Plot (P)	0.069	0.241	0.052	0.158	0.043	0.147
Interaction	0.214	0.612	0.160	0.457	0.133	0.380

Table 6: Effect of drought stress on relative water content (%) at 30, 60 and 90 DAS in sorghum genotypes (Pooled 2021-22 and 2022-23)

Genotypes		Leaf relative water content								
		30DAS			60DAS			90DAS		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	79.04	85.32	82.18	82.84	78.02	80.43	69.68	63.08	66.38
2	SVD-1358R	87.65	86.66	87.16	84.12	78.71	81.42	72.96	68.05	70.51
3	SVD-1528R	87.35	76.88	82.12	83.13	76.44	79.78	75.35	67.65	71.50
4	SVD-1403R	85.43	75.72	80.57	82.78	77.32	80.05	78.02	71.14	74.58
5	SPV-486	91.98	86.92	89.45	84.70	80.92	82.81	79.62	75.06	77.34
6	SPV-2217	83.75	83.85	83.80	83.52	78.89	81.21	79.56	72.96	76.26
7	CSV-216R	86.57	80.76	83.66	82.20	78.58	80.39	77.22	69.18	73.20
8	CSV-29R	87.56	90.87	89.21	85.39	80.98	83.19	74.82	69.79	72.31
9	ICSR-15001	83.36	76.35	79.85	82.30	75.70	79.00	67.64	61.35	64.49
10	Basavana pada	80.77	85.72	83.25	84.18	79.35	81.77	70.39	65.33	67.86
11	Tandur L	87.23	85.69	86.46	82.81	75.67	79.24	73.32	60.84	67.08
12	Phule Anuradha	91.26	88.77	90.01	85.70	82.91	84.30	74.77	70.47	72.62
13	Chitapur - L	81.86	80.72	81.29	83.07	75.10	79.09	76.16	65.04	70.60
14	DKS- 35	91.03	89.57	90.30	86.00	82.91	84.45	78.29	74.58	76.44
15	M-35-1	90.17	90.63	90.40	84.69	81.69	83.19	79.56	75.62	77.59
16	M 148-138	88.20	91.76	89.98	83.25	77.52	80.39	77.86	67.32	72.59
17	Basavan moti	90.43	86.47	88.45	84.32	80.83	82.57	77.94	74.46	76.20
18	Phule Vasudha	89.50	91.32	90.41	82.63	78.73	80.68	79.06	75.04	77.05
19	BJV-44	90.14	84.12	87.13	86.03	83.01	84.52	79.59	75.36	77.48
20	ICSR- 13025	84.84	84.17	84.50	82.30	77.10	79.70	69.73	64.02	66.88
Mean		86.91	85.11	86.01	83.80	79.02	81.41	75.58	69.32	72.45

	S.Em. ±	CD @ 5%	S.Em. ±	CD @ 5%	S.Em. ±	CD @ 5%
Main plot (M)	0.087	0.312	0.035	0.145	0.017	0.048
Sub Plot (P)	1.813	5.035	1.846	5.454	1.656	4.641
Interaction	5.588	NS	5.689	16.288	5.104	14.613

Grain yield per plant

Analysis of grain yield data revealed significant differences between irrigated and rainfed conditions, genotypes, and their interactions (Fig. 1). The irrigated condition yielded a mean of 70.23 grams per plant, significantly higher than the rainfed condition, which had a mean of 54.54 grams per plant. Among genotypes, BJV-44 had the highest yield (78.13 grams per plant), followed by M-35-1 (76.69 grams), DKS-35 (75.84 grams), and Phule Anuradha (75.47 grams). SVD-1272R (43.66 grams) and Chitapur-L (48.59 grams) had the lowest yields. M-148-138 and Tandur L experienced the most significant reductions under rainfed conditions, with drops of 34.3 grams and 30.9 grams, respectively, compared to their yields under irrigation. In contrast, BJV-44 and M-35-1 showed the smallest reductions, indicating better performance under water stress.

Table 7: Effect of drought stress on membrane stability index (%) at 30, 60 and 90 DAS in sorghum genotypes (Pooled 2021-22 and 2022-23)

	Genotypes	Membrane stability index								
		30DAS			60DAS			90DAS		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	SVD-1272R	86.45	82.00	84.23	72.97	68.31	70.64	59.88	47.57	53.72
2	SVD-1358R	84.72	85.42	85.07	75.81	71.56	73.68	63.41	54.22	58.81
3	SVD-1528R	82.00	87.23	84.62	78.27	72.87	75.57	64.63	52.78	58.70
4	SVD-1403R	87.24	88.62	87.93	80.76	75.63	78.19	71.23	55.69	63.96
5	SPV-486	90.30	89.43	89.86	83.74	79.22	81.48	75.26	63.78	69.52
6	SPV-2217	85.46	84.96	85.21	74.23	68.43	71.33	63.26	50.93	57.09
7	CSV-216R	87.81	88.71	88.26	81.59	76.47	79.03	72.51	57.78	65.14
8	CSV-29R	91.56	89.87	90.72	84.89	80.51	82.70	76.74	63.39	70.06
9	ICSR-15001	87.59	88.88	88.24	82.09	77.11	79.60	72.87	58.11	65.49
10	Basavana pada	86.73	85.34	86.04	75.17	69.87	72.52	61.95	53.22	57.58
11	Tandur L	87.72	87.84	87.78	80.02	74.98	77.50	69.97	55.76	62.86
12	Phule Anuradha	89.36	92.05	90.71	87.72	83.68	85.70	82.17	69.27	75.72
13	Chitapur - L	87.07	87.33	87.20	78.59	73.64	76.12	68.91	54.81	61.86
14	DKS- 35	90.34	91.95	91.14	86.94	83.24	85.09	80.60	68.73	74.66
15	M-35-1	88.98	88.98	88.98	82.69	78.17	80.43	74.21	64.78	69.49
16	M 148-138	86.79	87.57	87.18	78.74	74.06	76.40	69.94	55.66	62.80
17	Basavan moti	89.03	89.48	89.25	83.97	79.87	81.92	76.33	64.87	70.60
18	Phule Vasudha	88.04	89.91	88.98	85.46	80.84	83.15	77.36	65.10	71.23
19	BJV-44	89.79	89.06	89.43	83.14	78.78	80.96	74.78	67.16	70.97
20	ICSR- 13025	87.82	91.16	89.49	86.31	81.34	83.82	78.17	66.63	72.40
	Mean	87.74	88.29	88.01	81.15	76.43	78.79	71.71	59.56	65.63

	30DAS S.Em. ±	30DAS CD @ 5%	60DAS S.Em. ±	60DAS CD @ 5%	90DAS S.Em. ±	90DAS CD @ 5%
Main plot (M)	0.050	0.195	0.727	2.244	1.142	4.517
Sub Plot (P)	0.236	1.003	0.312	1.068	0.414	1.801
Interaction	0.729	2.086	0.963	2.756	1.276	4.654

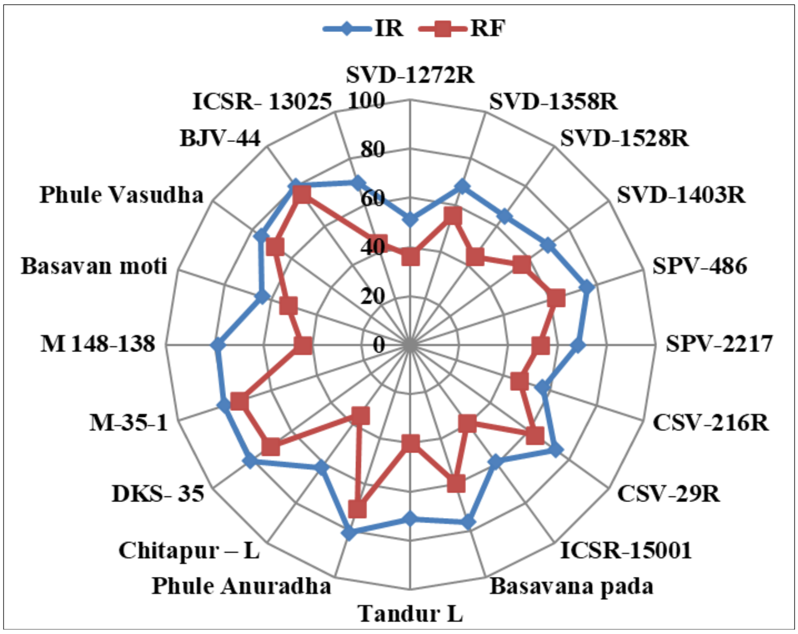

Fig 1: Variation in grain yield per plant among twenty sorghum genotypes under rainfed and irrigated conditions

The correlation coefficients between the Physiological parameters and grain yield

The physiological parameters analyzed in this study showed strong associations with grain yield, indicating their importance in determining crop productivity. At 30 days after sowing, there was no significant difference between rainfed and irrigated conditions. However, after flowering, changes in physiological parameters under water stress directly correlated with the yield responses of sorghum genotypes. Under rainfed conditions, SPAD values at 60 DAS exhibited a strong positive correlation with grain yield per plant (GY/P) (r = 0.942), indicating that higher SPAD values at 60 days after sowing are associated with increased yield (Fig. 2). Similarly, SPAD values at 90 DAS also showed a strong positive correlation with GY/P (r = 0.818). Total chlorophyll content (TLC) at 60 DAS and 90 DAS had strong positive correlations with GY/P (r = 0.912 and r = 0.908, respectively). Relative water content (RWC) at 60

DAS and 90 DAS also showed strong positive correlations with GY/P (r = 0.877 and r = 0.811, respectively). Membrane stability index (MSI) at 60 DAS and90 DAS had moderate positive correlations with GY/P (r = 0.534 and r = 0.685, respectively). Under irrigated conditions (Fig 3), the correlation values between physiological parameters and grain yield per plant (GY/P) were generally lower compared to rainfed conditions. SPAD values at 60 DAS showed a correlation with GY/P of 0.543, which is lower compared to rainfed conditions. TLC at 90 DAS had a correlation with GY/P of 0.62, also lower than in rainfed conditions. RWC at 60 DAS and 90 DAS showed correlations with GY/P of 0.665 and 0.461, respectively. MSI at 90 DAS recorded a correlation with GY/P of 0.486. These lower correlation values under irrigated conditions suggest that uniform moisture availability tends to lessen the variability and impact of physiological parameters on yield, compared to the more variable and stress-sensitive conditions of rainfed environments.

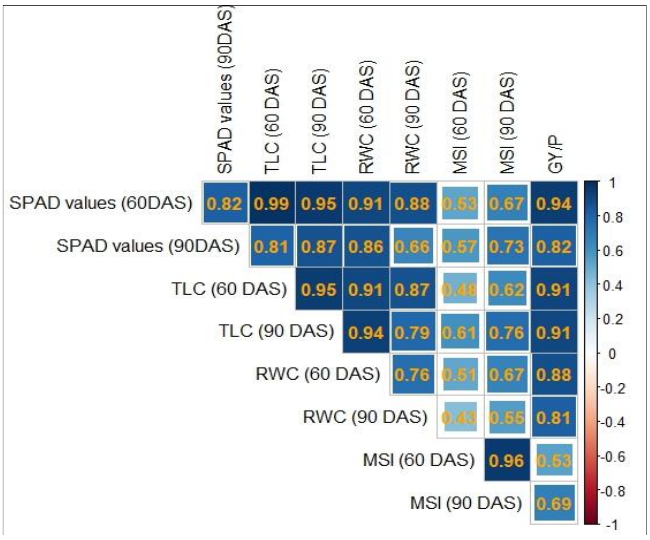

Fig 2: Correlation Coefficient Plot of Physiological Performance and Yield in Sorghum Genotypes Under Irrigated Conditions

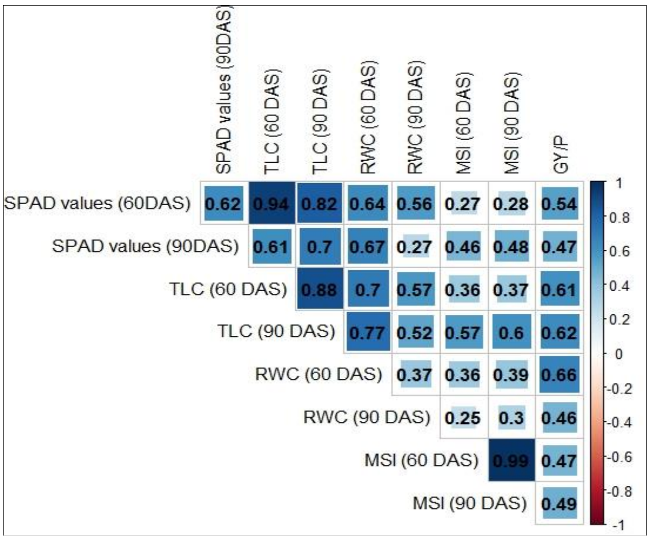

Fig 3: Correlation Coefficient Plot of Physiological Performance and Yield in Sorghum Genotypes Under Irrigated Conditions

Discussion

Our study demonstrated that drought stress significantly reduces chlorophyll content and leaf greenness in sorghum plants, as measured by SPAD values. Genotype M-35-1 maintained the highest SPAD values under both rainfed and irrigated conditions, indicating its superior chlorophyll retention under stress. In contrast, Chitapur - L exhibited the lowest SPAD values under rainfed conditions, reflecting its vulnerability to drought. These findings are consistent with Batista *et al*. (2018) [6] and Borrell *et al*. (2014) [7], who reported that water deficits reduce chlorophyll content by downregulating biosynthesis genes and upregulating degradation genes. Additionally, Kiran *et al*. (2018) [10] noted that drought-resistant sorghum lines maintain higher chlorophyll levels, supporting our observations.

Relative leaf water content (RWC) also decreased significantly under drought conditions, highlighting the impact of water stress on sorghum physiology. Genotypes like Basavan moti exhibited minimal reduction in RWC, demonstrating better water retention, while Tandur L showed a higher reduction, indicating greater susceptibility to drought. These findings align with Adotey *et al*. (2021) [2] and Pawar and Gagakh (2016) [13], who reported that decreased RWC due to increased transpiration and reduced water uptake affects various physiological processes. Lum *et al*. (2014) [12] similarly observed that drought conditions compromise cellular membrane integrity, as indicated by decreased membrane stability index (MSI) values.

Grain yield analysis revealed significant variations among genotypes under different water conditions. Genotypes BJV-44 and M-35-1 showed minimal yield reduction under rainfed conditions, indicating their drought resilience, while M 148-138 and Tandur L experienced substantial yield declines. These results are in line with Abderhim *et al*. (2017) [1], who noted that water scarcity reduces stomatal conductance and assimilate production essential for grain filling. Additionally, drought stress was found to reduce the harvest index (HI), as reported by Souza *et al*. (2021) [17], due to decreased above-ground biomass and impaired assimilate allocation towards grain production.

Our findings also highlighted significant positive correlations between SPAD chlorophyll readings, RWC, MSI, and grain yield under rainfed conditions. The strong correlations indicate that higher chlorophyll content and better water retention contribute to increased yield potential under drought stress. This is supported by Ravali *et al*. (2021) [15] and Dhutmal *et al*. (2015) [8], who emphasized the importance of these parameters in determining crop productivity under limited water availability. The variability in physiological responses under rainfed conditions makes these parameters more indicative of yield performance, underscoring their importance in stress environments.

Conclusion

This study aimed to identify drought-tolerant sorghum genotypes by evaluating their physiological parameters and yield performance under different moisture conditions during the rabi seasons of 2021-22 and 2022-23. The experiment, conducted using a split-plot design with two replications, revealed significant variations in chlorophyll content and relative water content (RWC) among twenty sorghum genotypes. Genotypes such as M-35-1, BJV-44, Basavan moti, DKS-35, and Phule Anuradha demonstrated superior physiological traits and yield performance under rainfed conditions, indicating their drought tolerance. In contrast, M-148-138 and Chitapur L showed significant reductions in these parameters, highlighting their susceptibility to drought. These findings provide valuable insights into the Physiological characteristics of sorghum genotypes, facilitating the selection of genotypes with enhanced growth, photosynthetic efficiency, drought tolerance, and reproductive development for specific water availability scenarios.

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Conflict of interest

Authors have declared that no Conflict of interest exist

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