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EFFECTS OF WATER STRESS ON FLOWERING PHENOLOGY AND YIELD-ATTRIBUTING CHARACTERISTICS OF SORGHUM GENOTYPES

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ABSTRACT

Sorghum (*Sorghum bicolor*) is a vital crop known for its resilience to drought, making it a promising candidate for cultivation in water-scarce regions. This study assessed the impact of water stress on the flowering phenology and yield attributes of twenty sorghum genotypes over two *rabi* seasons (2021-22 and 2022-23) under both rainfed and irrigated conditions. Using a split-plot design with two replications, the research aimed to identify genotypes with superior drought tolerance and understand their physiological responses to varying water availability. Results indicated significant genotype-by-environment interactions affecting days to flowering, physiological maturity, and yield parameters. Under irrigated conditions, genotypes such as Phule Anuradha and DKS-35 exhibited early flowering, with Phule Anuradha achieving 63 days and DKS-35 62 days to flowering. In contrast, under rainfed conditions, these genotypes flowered even earlier, indicating their adaptive mechanisms to escape severe drought. Notably, days to physiological maturity were shorter under rainfed conditions, with Phule Anuradha and SVD-1272R maturing in 104 and 105 days, respectively. Grain yield per plant varied significantly, with BJV-44 and Phule Anuradha yielding the highest under irrigated conditions and maintaining relatively high yields under rainfed conditions. Genotypes M-148-138 and ICSR-13025 experienced the greatest reductions in yield under drought stress, highlighting their susceptibility. The harvest index also varied, with Basavana Pada consistently showing high values across both conditions, suggesting better resource allocation and drought adaptation. Overall, the study identified M-35-1, BJV-44, Basavana Motti, DKS-35 and Phule Anuradha as drought-tolerant due to their consistent performance under water stress. In contrast, M-148-138 and Chitapur L were less resilient, underscoring the need for targeted breeding strategies to enhance drought tolerance in sorghum. These findings highlight the importance of selecting drought-tolerant genotypes to improve sorghum production in water-scarce conditions.

Key words : Sorghum, Irrigated, Rainfed, Flowering phenology and Yield.

Introduction

Sorghum is a C4 plant that evolved in Africa 50-70 million years ago after diverging from rice (Wolfe *et al.*, 1989). It is a valuable global crop grown for food, feed, fiber, and fuel (Paterson *et al.*, 2008). Sorghum is considered a crop for the future due to changing global climate trends and the increased use of marginal lands for agriculture (Paterson *et al.*, 2008). The global population is predicted to rise from about 7 billion to 9 billion by 2050, with most of this increase occurring in Sub-Saharan Africa, where population growth is highest (Haub, 2013). In Ethiopia, sorghum is widely grown in highlands, lowlands, and semi-arid regions, particularly in moisture-stressed areas where other crops struggle to survive (Tesso *et al.*, 2008). However, sorghum production in Ethiopia has declined due to population growth, land degradation, use of traditional farming implements, and global climate change (Adugna, 2007). Drought is a major cause of underproduction (Adugna, 2007).

Drought response in sorghum occurs in two distinct stages: pre-flowering and post-flowering (Tuinstra *et al.*, 1996). The Stay-Green (SG) trait is an integrated drought adaptation mechanism in sorghum (Borrell *et al.*, 2014). Severe drought during post-flowering stages can lead to chlorophyll loss and increased leaf senescence (Bray, 1993). Water deficit directly reduces grain and forage production and affects some morphophysiological characteristics of plants. Despite being one of the most drought-tolerant cereals, sorghum is still impacted by long periods of drought. Water stress reduces the chlorophyll index, the number of green leaves (Reddy, 2019), plant height, panicle harvest index, grain number, grain weight, and total yield (Menezes *et al*., 2015; Batista *et al*., 2019).

The effects of water deficit in sorghum vary depending on whether the stress occurs pre- or post-flowering (Wagaw, 2019). The plant's physiological response to drought tolerance can differ according to the severity and duration of the stress, the phenological stage, and the genetic material (Shao *et al*., 2008). Pre-flowering stress leads to leaf curl and discoloration, while post-flowering stress causes symptoms such as premature death, stem collapse, and lodging (Belete, 2018). Understanding how crops respond to these effects is crucial for developing and selecting drought-tolerant genotypes. Although much is known about the mechanisms that confer water stress tolerance in sorghum, it is essential to understand how the plant reacts to factors that limit its development under adverse conditions at different growth stages. This knowledge is necessary to enable more widespread sorghum cultivation, especially in regions with significant water stress challenges. Therefore, the objective of the present study was to investigate the effects of water stress on the flowering phenology of sorghum genotypes and how changes in flowering duration correlate with yield parameters.

Materials and Methods

Design and layout

In the *rabi* seasons of 2021-22 and 2022-23, a split-plot design experiment was conducted with two replications. Twenty sorghum genotypes (Table 1) were grown under two different moisture conditions to characterize their Phenological and yield-determining features.

Observations recorded

To determine how water stress affects growth, development, and production of sorghum genotypes, the observations were recorded at regular intervals during the study. The specifics of the observations that were made and the standard operating procedures that were implemented are outlined in the following paragraphs.

Days to flower initiation

The number of days taken for the first flower to open was noted in three individually tagged plants and was measured in days.

Days to 50 per cent flowering

The number of days from sowing to 50 per cent flowering were noted when 50 per cent of plants in each treatment flowered and was expressed in days.

Days to physiological maturity

The physiological maturitywas measured by recording the number of days required for a genotype to reach a stage where the seeds had formed a dark spot. This stage was identified when a dark spot (black layer) appears at the basal portion of seed whose appearance signals the end of photosynthate supply to the seed (Rao *et al*., 2007).

Total dry matter production and its partitioning at harvest

Three tagged plants were uprooted and separated into stem, leaf and ear head. These samples were first air-dried and then oven-dried at 65-70^{0}C till constant dry weight obtained and the dry weight was recorded.

Grain yield per plant (g)

The panicle heads were threshed, and the resulting cleaned average grain weight per head was quantified and expressed in grams.

Harvest index (%)

The Harvest Index (HI) was calculated using the formula provided by Donald (1962), which involves dividing the economic yield by the biological yield and then multiplying by 100 to express it as a percentage.

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

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

Statistical analysis and interpretation of data

The analysis and interpretation of data was done using the Fisher's method of analysis and variance technique as given by Panse and Sukhatme (1967). The level of significance used in "F" and "t" test was at 5% probability level and wherever "F" test was found significant, the "t" test was performed to estimate critical differences among various treatments. Two factorial CRD (complete randomized design) was used to analyze data of experiment was analyzed by split plot design.

Results and Discussion

Days to First Flowering and Days to 50% flowering

In response to drought stress, sorghum plants may exhibit early flowering as a survival strategy. This adaptive behavior allows them to complete their reproductive cycle before severe water scarcity sets in (Talwar *et al*., 2010). Both Phule Anuradha and DKS-35 showed evidence of early flowering under both stress and non-stress conditions (Table 2). During the first season (2021-22), under irrigated conditions, Phule Anuradha flowered at 63 days after emergence, while DKS-35 flowered at 62 days (Table 2). Under rainfed conditions, both varieties exhibited early flowering, with both attaining flowering at 58 days after emergence under non-stress conditions.

The days to 50% flowering varied significantly among genotypes, irrigation or rainfed environments, and their interactions. Under irrigated conditions, the mean number of days to 50% flowering was significantly higher, around 80 days in both seasons, followed by the rainfed condition, which was around 74 days. Chitapur L recorded considerably more days to 50% flowering under irrigated conditions, with 93 days in 2021-22 and 94 days in 2022-23, followed by ICSR-13025, with 90 days in 2021-22 and 91 days in 2022-23. In contrast, under rainfed conditions, Phule Anuradha (61 days in 2021-22 and 62 days in 2022-23) and DKS-35 (62 days in both seasons) had the shortest durations to 50% flowering.

Days to physiological maturity

According to Table 2, the mean days to physiological maturity were significantly higher under irrigated conditions, with 127 days in 2021-22 and 122 days in 2022-23. In contrast, the rainfed condition showed the lowest mean days to physiological maturity, with 117 days in 2021-22 and 113 days in 2022-23. In the first season, the genotypes Phule Anuradha and SVD-1272R exhibited early physiological maturity, taking 112 and 117 days respectively under irrigated conditions, and 104 and 105 days respectively under rainfed conditions. In the second season, Phule Anuradha and CSV-216R showed early physiological maturity, taking 105 and 111 days respectively under irrigated conditions and Phule Anuradha and SVD-1272R took 101 and 102 days respectively under rainfed conditions.

Tolerant genotypes are identified based on their ability to maintain relatively shorter flowering and maturity periods under stress conditions compared to susceptible genotypes. These tolerant genotypes typically exhibit early flowering and achieve physiological maturity earlier or within a timely manner under stress conditions, allowing them to complete their life cycle and produce viable seeds before adverse conditions become too severe (Jabereldar *et al.*, 2017). Similarly, sorghum plants speed up their reproductive and maturation processes in drought conditions to finish their life cycle and produce viable seeds before a serious water shortage occurs. Our findings indicate that genotypes under rainfed conditions took fewer days to reach physiological maturity. Tolerant genotypes showed early flowering to escape severe drought at later stages, but they maintained consistent flowering days under both stress and non-stress conditions, which increased the number of days required for grain filling. Basavan Motti and Phule Anuradha maintained consistent flowering days under both irrigated and rainfed conditions, whereas Tandur L and Chitapur L showed high variation in flowering days.

Plant biomass

Drought stress markedly affects leaf dry weight, stem dry weight, and panicle dry weight in sorghum genotypes. In a study of 20 genotypes, DKS-35 achieved the highest leaf dry weight under rainfed conditions in the first season (35.22 g), while BJV 44 had the highest leaf dry weight under irrigated conditions (39.6 g) (Fig. 1). In the second season, SPV-486 exhibited the highest leaf dry weight in both irrigated (40.49 g) and rainfed conditions (37.51 g). Limited water availability reduces leaf dry weight by diminishing leaf area, thickness, and cell expansion, as reported by Pawar and Gadakh (2018).

Drought stress also negatively impacts stem dry weight by affecting cell elongation and division, resulting in reduced stem growth and biomass accumulation, as noted by Saberi and Aishah (2013). Insufficient water limits the production of structural materials necessary for stem development, leading to a decline in stem dry weight. Under rainfed conditions, M-35-1 recorded the highest stem dry weight in both seasons (125.06 g and 123.21 g, respectively). In the first season, the Basavanmotti genotypes showed minimal reduction in

Table 2 : Effect of drought stress on days to first flowering, 50 % flowering and physiological maturity in sorghum genotypes (2021-22 and 2022-23).

	Genotypes	2021-22									2022-23								
		Days to first flowering			Days to 50% flowering			Days to physiological maturity			Days to first flowering			Days to 50% flowering			Days to physiological maturity		
		IR	RF	Mean	IR	RF	Mean	IR	RF	Mean	IR	RF	Mean	IR	RF	Mean	IR	RF	Mean
1	**SVD-1272R**	67	61	**64**	74	67	**71**	117	105	**111**	66	62	**64**	76	68	**72**	113	102	**107**
2	**SVD-1358R**	77	71	**74**	81	77	**79**	131	121	**126**	78	73	**76**	83	77	**80**	129	117	**123**
3	**SVD-1528R**	80	73	**76**	85	77	**81**	132	121	**127**	78	70	**74**	86	79	**83**	130	119	**125**
4	**SVD-1403R**	79	70	**75**	83	74	**78**	125	115	**120**	75	68	**72**	80	73	**77**	121	112	**116**
5	**SPV-486**	76	70	**73**	77	75	**76**	128	119	**124**	73	69	**71**	77	73	**75**	121	115	**118**
6	**SPV-2217**	79	73	**76**	86	77	**82**	133	123	**128**	79	73	**76**	86	79	**83**	125	116	**121**
7	**CSV-216R**	68	62	**65**	72	67	**69**	117	105	**111**	68	64	**66**	74	68	**71**	111	104	**107**
8	**CSV-29R**	73	68	**71**	76	70	**73**	120	111	**115**	72	67	**69**	77	71	**74**	114	107	**111**
9	**ICSR-15001**	81	73	**77**	86	78	**82**	137	124	**131**	78	71	**74**	85	76	**80**	132	121	**127**
10	**Basavan pada**	72	67	**70**	76	72	**74**	126	116	**121**	73	68	**70**	76	71	**73**	120	114	**117**
11	**Tandur L**	81	72	**76**	88	79	**84**	130	117	**124**	77	69	**73**	88	78	**83**	126	110	**118**
12	**Phule annuradha**	63	58	**60**	66	61	**63**	112	104	**108**	62	58	**60**	65	62	**63**	105	101	**103**
13	**Chitapur - L**	88	80	**84**	93	86	**90**	139	125	**132**	89	79	**84**	94	83	**89**	134	121	**127**
14	**DKS- 35**	62	58	**60**	67	62	**64**	119	110	**115**	65	59	**62**	69	62	**65**	112	102	**107**
15	**M-35-1**	67	65	**66**	70	66	**68**	118	111	**115**	69	66	**68**	72	69	**71**	112	103	**107**
16	**M 148-138**	76	69	**73**	81	75	**78**	127	115	**121**	77	71	**74**	83	76	**80**	126	114	**120**
17	**Basavan motti**	76	72	**74**	78	74	**76**	129	120	**125**	74	72	**73**	80	75	**78**	123	118	**120**
18	**Phule vasudha**	74	71	**72**	78	75	**76**	134	119	**127**	75	73	**74**	81	75	**78**	128	120	**124**
19	**BJV-44**	84	78	**81**	84	80	**82**	133	125	**129**	79	78	**79**	85	80	**83**	125	117	**121**
20	**ICSR- 13025**	85	80	**83**	90	86	**88**	138	127	**133**	86	80	**83**	91	85	**88**	136	125	**131**
Mean		**75**	**69**	**72**	**80**	**74**	**77**	**127**	**117**	**122**	**75**	**70**	**72**	**80**	**74**	**77**	**122**	**113**	**117**
		S.Em.±	**CD @5%**		**S.Em.±**	**CD @5%**		**S.Em.±**	**CD @5%**		**S.Em.±**	**CD @5%**		**S.Em.±**	**CD @5%**		**S.Em.±**	**CD @5%**	
Mainplot(M)		0.050	0.175		0.107	0.355		0.173	0.302		0.027	0.079		0.063	0.185		0.117	0.482	
SubPlot(P)		1.581	6.090		1.697	4.563		2.591	7.923		1.590	5.208		1.707	4.687		2.609	7.148	
Interaction		4.873	13.952		5.231	14.975		7.986	22.864		4.902	14.034		5.261	15.061		8.041	23.020	

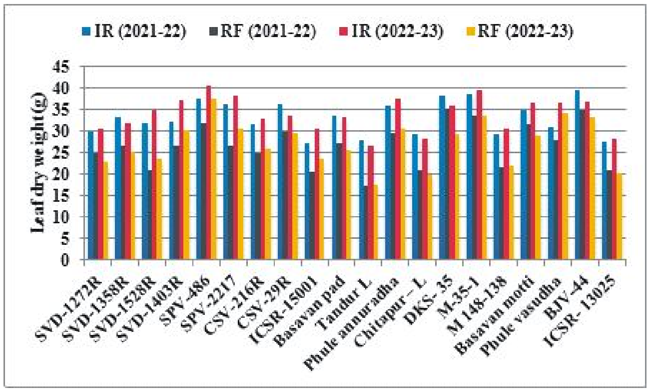

Fig. 1 : Effect of drought stress on Leaf Dry weight in Sorghum genotypes.

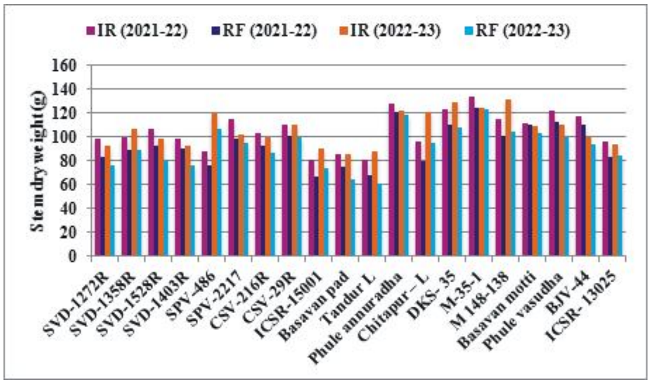

Fig. 2 : Effect of drought stress on Stem Dry weight in Sorghum genotypes.

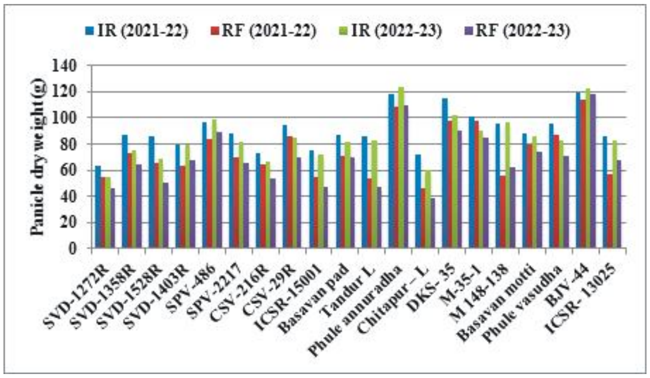

Fig. 3 : Effect of drought stress on Panicle dry weight in Sorghum genotypes.

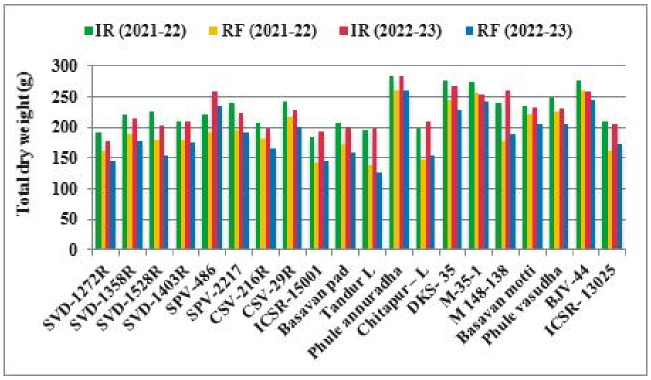

Fig. 4 : Effect of drought stress on Total dry weight in Sorghum genotypes.

stem dry weight under stress (111.98 g under irrigated and 110.52 g under rainfed conditions), while BJV 44 exhibited minimal reduction in the second season (99.61 g under irrigated and 93.45 g under rainfed conditions) (Fig. 2).

Sorghum panicle weight decreases under drought conditions due to the plant's physiological responses to limited water availability, as highlighted by Phuong *et al.* (2019). Drought stress adversely affects overall growth and development, resulting in reduced panicle weight. Water scarcity forces sorghum plants to allocate resources toward survival rather than reproductive processes such as panicle development and grain filling, as described by Khatab *et al.* (2017). Consequently, panicles develop fewer and smaller grains, leading to reduced weight. The study results show that BJV 44 recorded the highest panicle dry weight in both seasons (114.26 g and 117.9 g, respectively). In the first season, M-35-1 had minimal reduction in panicle dry weight under stress conditions (101.23 g under irrigated and 97.39 g under rainfed conditions), while in the second season, BJV 44 showed minimal reduction (122.74 g under irrigated and 117.9 g under rainfed conditions) (Fig. 3). Additionally, drought stress restricts photosynthesis, reducing carbohydrate production necessary for panicle development. Overall, the impact of drought stress on leaf, stem, and panicle dry weight in sorghum genotypes disrupts various physiological processes, including cell expansion, growth, and assimilate availability, ultimately leading to a reduction in total dry weight (Fig. 4).

Grain yield per plant

The data analysis for grain yield revealed significant differences between irrigated and rainfed conditions, genotypes and their interactions (Fig. 5). Under irrigated conditions, the mean grain yield was significantly higher, with 73.51 grams per plant during the first season and 61.87 grams per plant in the second season. In contrast, under rainfed conditions, the mean grain yields were significantly lower, with 57.3 grams per plant in the first season and 52.81 grams per plant in the second season (Fig. 5B). Abderhim *et al.* (2017) highlighted that water scarcity affects stomatal conductance, leading to decreased carbon dioxide uptake for photosynthesis. This result in limited assimilate production, which is crucial for grain filling and yield formation.

In the first season (Fig. 5A), under rainfed conditions, genotypes BJV-44 and M-35-1 recorded the highest grain yields per plant, with 78.92 and 73.32 grams per plant, respectively. Under irrigated conditions, BJV-44 and Phule

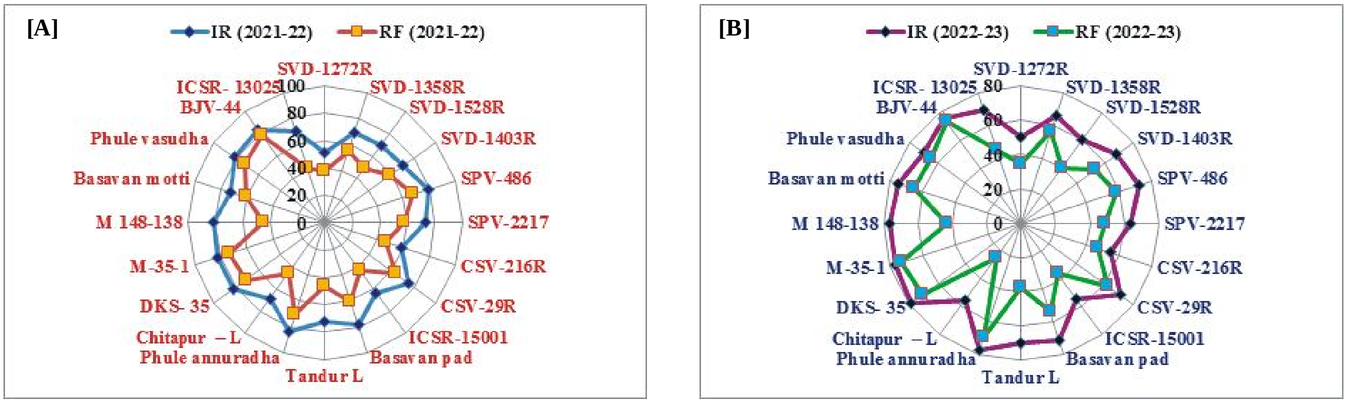

Fig. 5 : Effect of Drought stress on Grain Yield per plant in Sorghum genotypes during 2021-22 (A) and 2022-23 (B).

Fig. 6 : Effect of Drought stress on Harvest Index (HI) in Sorghum genotypes during 2021-22 (C) and 2022-23 (D).

Anuradha recorded the highest grain yields per plant, with 84.39 and 83.58 grams per plant, respectively. Conversely, SVD-1272R recorded the lowest grain yields per plant under both rainfed and irrigated conditions, with 38.11 and 51.77 grams per plant, respectively. In the second rabi season, BJV-44 maintained the highest grain yield per plant under both rainfed and irrigated conditions, with 78.92 and 84.39 grams per plant, respectively.Notably, genotypes M 148-138 and ICSR-13025 exhibited the most significant reductions in grain yield per plant under rainfed conditions. M 148-138 experienced a reduction of 35.63 grams, while ICSR-13025 had a reduction of 27.48 grams in grain yield compared to irrigated conditions (80.83 and 69.88 grams per plant under irrigated conditions, and 45.2 and 42.4 grams per plant under rainfed conditions, respectively). In contrast, genotypes BJV-44 and Phule Vasudha showed the least drop in grain yield per plant under rainfed conditions, with 84.39 and 81.25 grams per plant under irrigated conditions, and 78.92 and 72.86 grams per plant under rainfed conditions, respectively. These findings suggest that while M 148-138 and ICSR-13025 performed well under non-stress conditions, they were unable to withstand induced water stress, resulting in a significant reduction in yields.

Harvest index

The harvest index (HI) is a crucial parameter that reflects the allocation of biomass between panicles and other above-ground biomass (Galyuon *et al.*, 2019). Souza *et al.* (2021) found that drought conditions significantly impact sorghum's physiological processes, leading to altered resource allocation and a reduction in the harvest index due to limited water availability. Our study observed significant variations in harvest index values between irrigated and rainfed conditions (Fig. 6). The irrigated condition consistently exhibited higher mean harvest indices of 31.70% and 30.21% in the first and second rabi seasons, respectively.

Fisher and Maurer (1978) noted that drought stress reduces total leaf chlorophyll content and leaf area, thus limiting the carbohydrates available for grain filling. Consequently, the plant's resources are redirected towards survival rather than reproduction, leading to a reduced proportion of biomass allocated to grain yield (Saeidi *et al.*, 2015). Under non-stress conditions, Basavana Pada consistently had the highest harvest index, with 37.85% and 35.55% in both seasons, followed by Tandur L with values of 37.06% and 35.31%, respectively. In the stress regime, Basavana Pada (35.03%) and SPV-486 (34.90%) had the highest harvest indices in the 2021-22 season (Fig. 6C), while Basavana Pada (34.17%) and Basavan Motti (31.73%) led in the 2022-23 season (Fig. 6D). These results indicate that Basavana Pada maintained a high harvest index under both stress and non-stress conditions, demonstrating its adaptability to varying water availability.

Conclusion

This study aimed to evaluate the phenological and yield-attributing characteristics of twenty sorghum genotypes over two rabi seasons (2021-22 and 2022-23) under rainfed and irrigated conditions. Significant variation was observed in flowering time, with ICSR-13025 and ICSR-15001 taking longer to reach 50% flowering under irrigated conditions, indicating slower reproductive development in favorable moisture. Conversely, Phule Anuradha and DKS-35 flowered earlier under rainfed conditions, showing better adaptation to water scarcity. In terms of yield and biomass production, Basavan moti and Phule Anuradha performed best under irrigation, while M-148-138 suffered substantial reductions in dry matter under rainfed conditions. BJV-44 and M-35-1 achieved relatively high grain yields in rainfed environments. Among the genotypes, M-35-1, BJV-44, Basavan moti, DKS-35, and Phule Anuradha were identified as drought-tolerant due to their superior performance in water-limited conditions, whereas M-148-138 and Chitapur L were deemed susceptible to moisture stress.

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Conflict of interest

Authors have declared that no Conflict of interest exist.

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