

## CLIMATIC VARIABILITY AND THERMOTOLERANCE IN SORGHUM (*SORGHUM BICOLOR* L.)

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### SUMMARY

Global climate change, characterized by rising temperatures and fluctuating rainfall, poses a major threat to sorghum productivity. The present study evaluated the physiological responses of two sorghum lines (AKR150 and C43) under field conditions during the 2024 and 2025 summer seasons at ICAR-IIMR, Hyderabad. Weather data indicated higher temperatures, reduced relative humidity, and increased sunshine hours in 2025, creating intensified heat stress conditions. Physiological traits-chlorophyll content (SCMR), canopy temperature depression (CTD) and membrane stability index (MSI) were significantly affected by the climatic variation. Both genotypes exhibited declines in chlorophyll content and MSI under 2025 heat stress; however, AKR150 maintained higher chlorophyll stability and greater CTD, indicating efficient canopy cooling and superior thermotolerance. Conversely, C43 showed higher MSI but experienced sharper chlorophyll loss, reflecting moderate tolerance. This study highlights the effects of climatic variability on sorghum physiology and identifies AKR150 as a promising genotype for breeding programs targeting the development of heat-resilient cultivars suited to future climate conditions.

**Key words:** Canopy temperature depression, climate change, Sorghum, SPAD chlorophyll meter reading

Global climate change has emerged as a major challenge to agricultural productivity, as rising temperatures and irregular rainfall patterns increasingly intensify heat stress conditions (IPCC, 2021). The combined effects of elevated temperature and erratic precipitation heighten both heat and drought stress, causing marked declines in crop yield, forage quality, and nutritional composition (Ostmeyer *et al.*, 2020; Fahad *et al.*, 2022). Sorghum grows optimally between 21 °C and 34 °C during seedling establishment and early growth, but temperatures beyond this range significantly hinder germination, reduce seedling vigor, and negatively affect overall crop development (Sravanthi *et al.*, 2025).

According to projections by the Intergovernmental Panel on Climate Change (IPCC, 2021), global mean temperatures are expected to increase by approximately 1.5°C to 3.2°C by the century's end, intensifying the effects of heat stress on agricultural crops. During the seedling phase, elevated temperatures disrupt essential physiological mechanisms such as photosynthesis, membrane

integrity, and enzymatic activity, while promoting the generation of reactive oxygen species (ROS) that cause oxidative damage (Goyal *et al.*, 2023; Gao *et al.*, 2023). These physiological impairments result in reduced vigor, poor establishment, and substantial declines in crop yield (Jagadish *et al.*, 2021).

Sorghum bicolor is a key cereal crop and resilient C4 species that produces both grain and fodder under low-input and harsh conditions (Hao *et al.*, 2021). It ranks globally as the fifth most important cereal after wheat, rice, maize and barley (Khalifa *et al.*, 2023). In India, it plays a major role among primary food-grains and its strength lies in thriving on marginal lands where other crops fail. This adaptability allows sorghum to compete strongly under given sufficient moisture and inputs (Kumar *et al.*, 2022).

In 2023-24, India had around 3.97 million ha under sorghum and produced approximately 4.74 million tonnes. (ANGRAU outlook Report, 2024). This crop holds particular significance for small-scale farmers in India's arid regions, where it serves primarily as a subsistence crop (Anbazhagan *et al.*, 2022).

Global research indicates that climatic factors significantly influence both the yield and quality seed production. This deficit highlights the growing need for enhanced seed production to meet current and future requirements. Consequently, a key challenge facing the seed sector involves developing improved cultivars capable of optimizing agricultural output under evolving climatic conditions (Ainsworth *et al.*, 2008; Bruins, 2009; Ceccarelli *et al.*, 2010).

Climate resilient crops such as grasses: Guinea grass, Bajra -Napier hybrids and Tri-specific hybrids, Dinanath grass, (Singh *et al.*, 2020; Dheeravathu *et al.*, 2021a; Dheeravathu *et al.*, 2021b; Dheeravathu *et al.*, 2022a; Dheeravathu *et al.*, 2022b, Antony *et al.*, 2021; Dheeravathu *et al.*, 2022b), pulses: cowpea, berseem, clitoria, centrosema, siratro (Dheeravathu *et al.*, 2017a; Dheeravathu *et al.*, 2017 b; Dheeravathu *et al.*, 2021a; Dheeravathu *et al.*, 2021c; Dheeravathu *et al.*, 2022b; Dheeravathu *et al.*, 2022c, Dheeravathu *et al.*, 2023), forage cereals including millets: pearl millet, kodo millet and sorghum (Singh *et al.*, 2010; Dheeravathu *et al.*, 2022a, Dheeravathu *et al.*, 2024; Dheeravathu *et al.*, 2024a and b; Malathi *et al.*, 2022; Amrutha *et al.*, 2023; Sravanthi *et al.*, 2024; sravanthi *et al.*, 2025), have been proven to be climate smart.

Given the increasing frequency of heat stress events, the development of heat-resilient sorghum cultivars has become vital to ensuring future food security (Nori *et al.*, 2020). Recent research has demonstrated significant genetic diversity among sorghum germplasm, with some genotypes showing superior tolerance to elevated temperatures through enhanced antioxidant activity, osmotic regulation, and cellular stability (Chen *et al.*, 2022; Lv *et al.*, 2021). The identification and characterization of such thermotolerant genotypes form the foundation for breeding strategies aimed at strengthening sorghum's adaptability to global warming. The present investigation focuses on assessing the physiological responses of diverse sorghum genotype in field condition under heat stress, thereby identifying key adaptive traits that confer tolerance. These results will support targeted breeding efforts to develop improved sorghum varieties capable of maintaining growth and yield under high-temperature environments.

## MATERIALS AND METHODS

The study was conducted in research farm at ICAR- Indian Institute of Millets Research (IIMR),

Rajendranagar, Hyderabad. It is located at Southern Telangana Zone of Telangana state. It is located at 17 19' 40.9" N latitude, 78 23' 38.2" E longitude, at an altitude of 542 meters above mean sea level.

## Seed materials

The sorghum lines were procured from ICAR-IIMR, Hyderabad, India. Two sorghum lines *ie.*, AKR150 and C43 were evaluated in this study. Sorghum seeds were surface sterilized (disinfected) with sodium hypochlorite (NaOCl) solution for 3 min and then thoroughly washed for 5 min with distilled water and these seeds were used for the experiments.

## Experimental details and Design

The study was carried out in 2024 and 2025 from 2<sup>nd</sup> week of January to 3<sup>rd</sup> week of May, for heat stress tolerance in summer season for high temperature. Meteorological weather data *ie.*, mean high and low temperature (Fig 1 (a)), Relative humidity (Fig 1 (b)), Rainfall, Rainy days (Fig 1 (c)), sunshine hours and wind speed (Fig 1 (d)) was collected from, Meteorological Weather Division, Agricultural Research Institute (ARI), PJTSAU, Rajendranagar, Hyderabad (Fig. 1). The experiment was conducted in completely randomized design (CRD) with 2 sorghum genotypes replicated thrice. The seeds were sown in the field with the plot size 3×4 cm<sup>2</sup> with the 60cm×15cm spacing after performing recommended cultural practices.

Observations were recorded on SPAD chlorophyll meter readings (SCMR), Canopy temperature depression (CTD) and Membrane stability index (MSI) at vegetative stage (50 days after sowing (DAS)).

## Chlorophyll content (SPAD)

SPAD (Soil Plant Analytical Development) Chlorophyll Meter Readings (SCMR) were recorded with Minolta chlorophyll meter (Model SPAD 502). In every tagged plant, total chlorophyll content was measured with SPAD and the readings were recorded on 3<sup>rd</sup> or 4<sup>th</sup> leaf from the top of each representative plant, between 9.00 AM to 11.00 AM of the day by keeping on the different position of the leaf in the slot of the meter head and the average of these readings was considered as the value of one plant. The readings of five tagged plants per each plot were averaged and

considered as SPAD chlorophyll meter reading of each plot.

### Membrane stability index (MSI)

A known weight of the leaf sample (0.1 g) cut into pieces of uniform size is taken in test tubes and the samples are kept in hot water bath at 40°C for 30 min in 10 ml of water for three hours, and the leakage is recorded by reading the initial absorbance at 273 nm, using a spectrophotometer. The samples are then incubated in a hot water bath (100 °C) for 10 min and the final absorbance at 273 nm recorded (Towill and Mazur, 1975). The percent membrane stability is calculated as follows:

$$\text{MSI} = (1 - C_f/C_i) \times 100$$

### Canopy temperature depression (CTD)

Canopy temperature depression measurements were made by using a handheld infrared thermometer (Model OS 530 HR, Omega Engineering Inc Stamford CT USA). The data were recorded per plot (genotype and replication wise) at approximately 0.5 m from the edge of the plot and approximately 45° from the horizontal. The measurements were recorded at top, middle and basal level at 14.00 hours on cloudless and bright days CTD was calculated using the following formula provided by Rosyara *et al.* (2008).

$$\text{CTD} = \text{air temperature} - \text{Canopy temperature}$$

### STATISTICAL ANALYSIS

Analysis of data was performed with Microsoft Excel statistical program using completely randomized design.

### RESULTS AND DISCUSSION

The results indicated that physiological characteristics *viz.* SCMR, CTD and MSI were

significantly ( $p < 0.05$ ) affected by climatic condition during 2024 and 2025.

### Weather influence on physiological traits:

Marked interannual variation was observed in the weather parameters between 2024 and 2025, which influenced the physiological responses of sorghum genotypes (Table 1). During January to May 2025, the average maximum temperature (Fig 1 (a)) ranged between 29°C and 39°C, while minimum temperature varied from 16°C to 27°C, both slightly higher than those recorded in 2024 (maximum: 31–42°C; minimum: 12–24°C) and is higher than the past 20 years' weather data. The increase in night temperature drastically affected the growth and development of the crop. The mean relative humidity (Fig. 1. (b)) was comparatively lower in 2025 (69–83%) than in 2024 (74–87%) during most standard meteorological weeks, especially between weeks 10 and 18, indicating drier air and greater evaporative demand. Additionally, sunshine hours were consistently higher in 2025 (8–10 hours/day) compared to 2024 (6–9 hours/day), while rainfall was minimal in both years but slightly higher in 2025 (up to 11 mm during SMW 16) than in 2024, suggesting intense heat and lower humidity stress during the 2025 season. Wind speed remained similar between years (3–5 km/h), exerting little differential influence.

Under these contrasting climatic conditions, significant differences were observed in chlorophyll content (SPAD/SCMR), canopy temperature depression (CTD), and membrane stability index (MSI) between lines and years. Elevated heat during 2025 led to reductions in chlorophyll content and MSI in both lines (Table 1), reflecting photosynthetic and cellular membrane impairment due to thermal stress.

Genotype AKR150 maintained higher chlorophyll stability (68.2 in 2024 and 64.3 in 2025; mean 66.3) compared to C43, which showed a sharp decline from 76.7 to 54.1 (mean 65.4). The decrease was more pronounced in C43, coinciding with the period of high temperature and low humidity between

TABLE 1  
Physiological performance of sorghum lines under climatic conditions.

Lines/Year	Chlorophyll content (SCMR)			CTD			MSI		
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
AKR150	68.2	64.3	66.3	1.5	5.4	3.5	77.1	70.4	70.4
C43	76.7	54.1	65.4	6.7	5.0	5.9	82.4	74.7	74.7

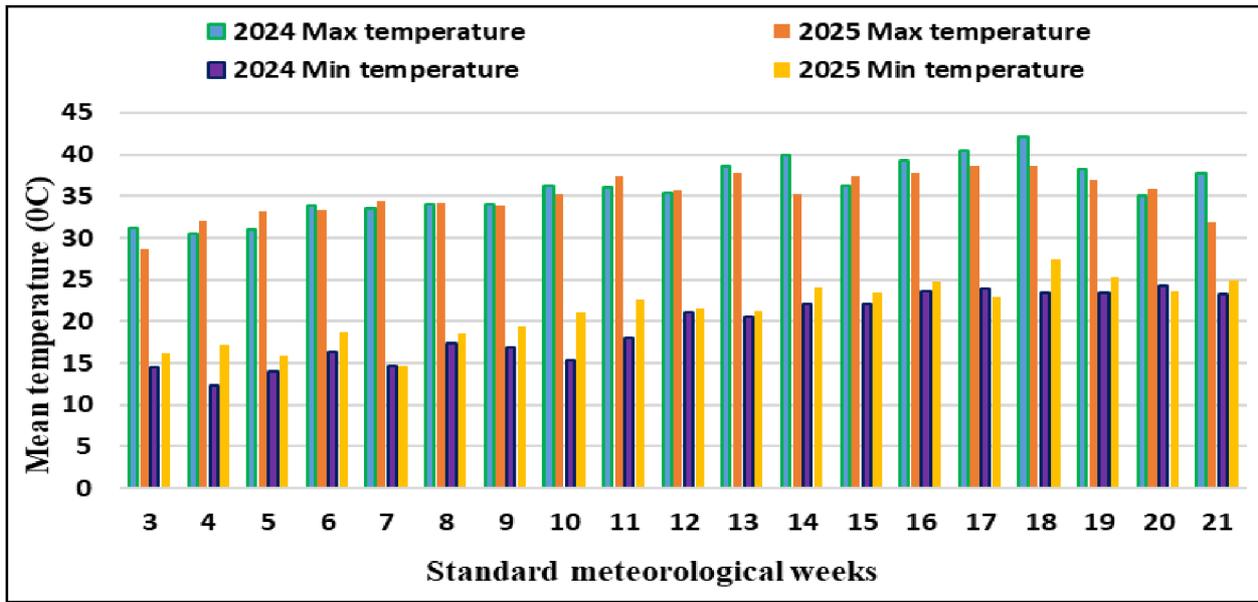


Fig. 1. Weather data during seedling growth period in 2024 and 2025.

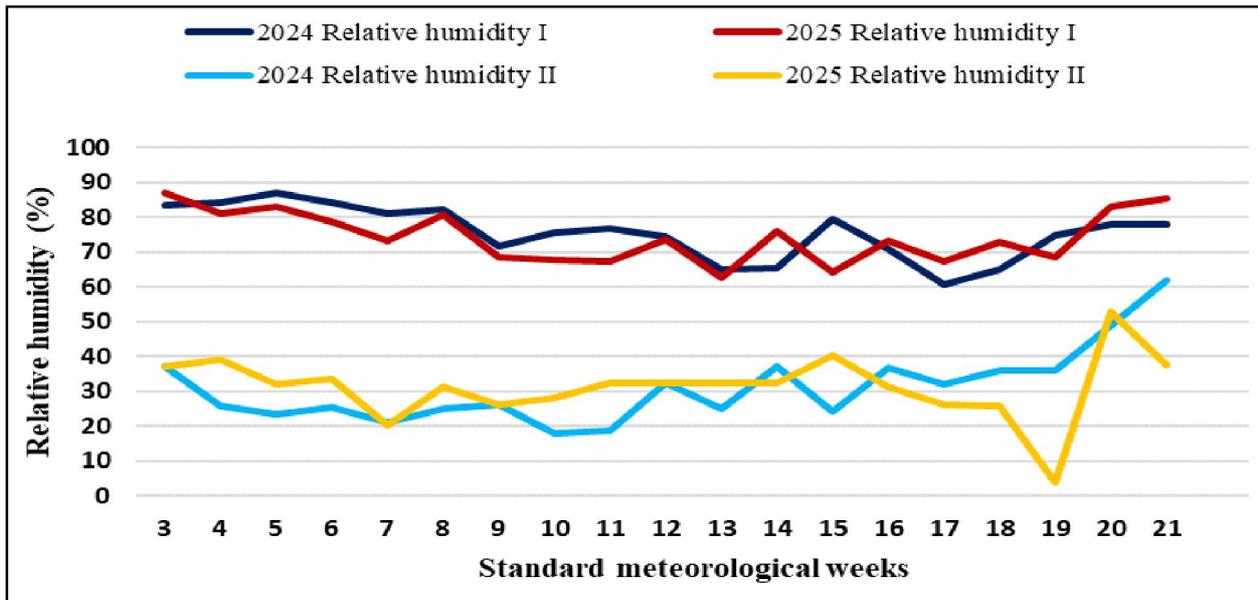


Fig. 1a. Temperature during crop growth period in 2024 and 2025.

SMW 11 and 17, when canopy stress was maximal. Canopy temperature depression (CTD) increased in AKR150 from 1.5°C to 5.4°C, indicating better canopy cooling ability under 2025 heat stress, whereas C43 recorded a marginal reduction in CTD (6.7°C to 5.0°C), implying less effective transpirational cooling. The membrane stability index (MSI) also declined in both lines under 2025 heat conditions (AKR150: 77.1 vs 70.4; C43: 82.4 vs 74.7), corresponding to periods of high sunshine intensity and elevated minimum temperatures. Despite this, C43 maintained a slightly

higher mean MSI (78.6) than AKR150 (73.7), suggesting better cellular membrane integrity across seasons.

High temperature and reduced humidity during 2025 adversely affected sorghum physiology, reducing chlorophyll content and membrane stability. AKR150 maintained better canopy cooling and chlorophyll retention, indicating superior thermotolerance. Similar findings were reported by Nouri *et al.* (2020) and Prasad *et al.* (2008), highlighting heat-induced damage to sorghum photosynthetic efficiency.

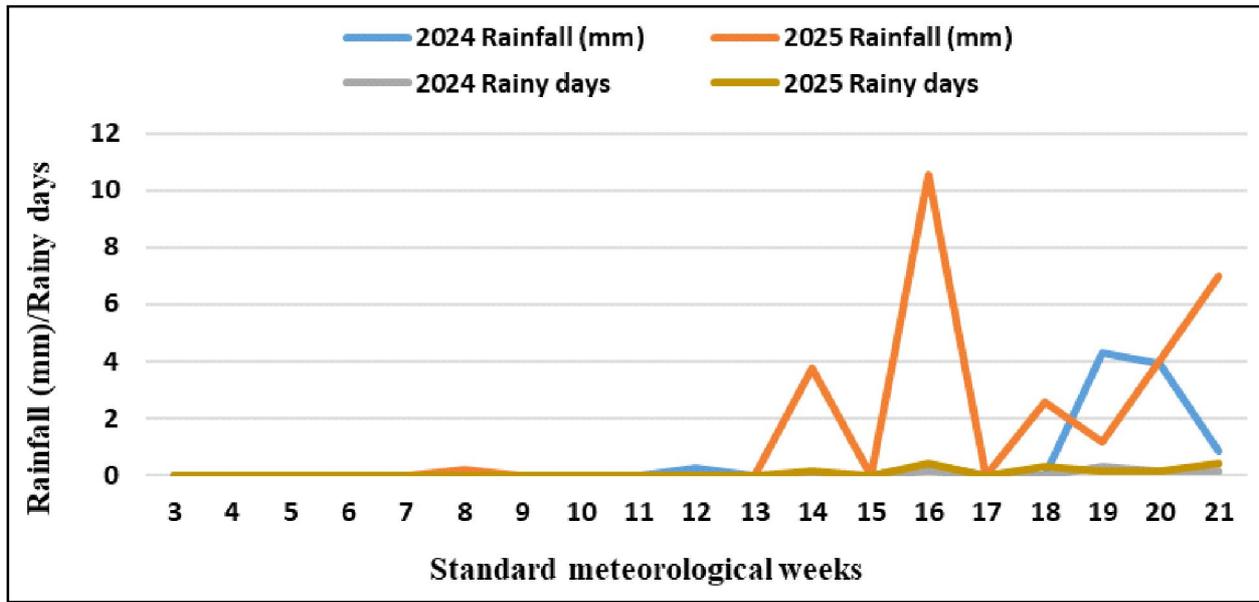


Fig. 1b. Relative humidity during crop growth period in 2024 and 2025.

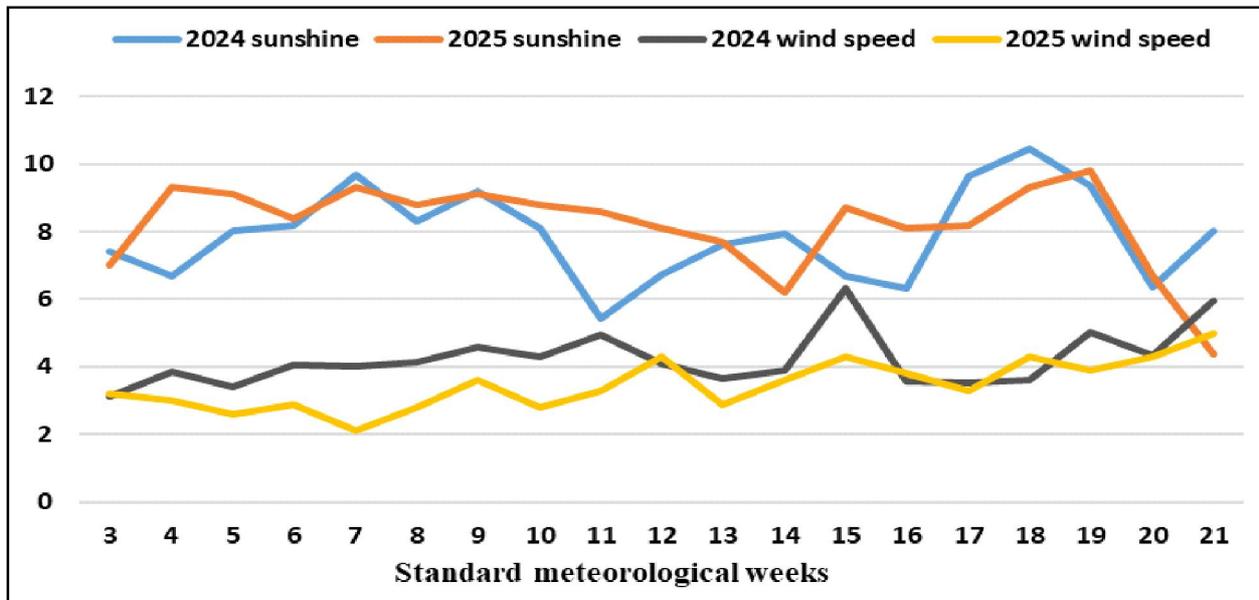


Fig. 1c. Rainfall and rainy days Sunshine and wind speed during crop growth period in 2024 and 2025.

**CONCLUSIONS**

The comparative analysis during 2025 season markedly influenced the physiological performance of sorghum lines, as evidenced by reduced chlorophyll content and membrane stability compared to 2024. The elevated temperature, prolonged sunshine duration, and reduced relative humidity collectively impaired photosynthetic efficiency and cellular integrity. Despite this, genotypic variation in thermotolerance was evident. AKR150 exhibited greater canopy temperature depression and sustained chlorophyll retention, indicating superior

transpirational cooling and heat resilience. In contrast, C43 showed higher membrane stability but greater chlorophyll degradation, reflecting partial tolerance. Overall, AKR150 demonstrated robust adaptive physiological mechanisms, making it a promising for breeding programs targeting heat-tolerant sorghum cultivars suited to climate-stressed environments.

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