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# Evaluation of Advanced Sorghum Lines for Heat Tolerance Under Agro-Ecological Conditions of Dera Ismail Khan, Pakistan

[1]Iqtidar Hussain, [1]Mohammad Inayat Ullah, [2]Sheheryar, [3]Muhammad Naeem and [3]Muhammad Mamoon-ur-Rashid

[1]Department of Agronomy, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan
[2]Project Management Unit, Pakistan Agricultural Research Council, Islamabad, Pakistan
[3]Department of Entomology, Gomal University, Dera Ismail Khan 29220, Pakistan

## ABSTRACT

**Background and Objective:** Sorghum is a vital cereal crop for Pakistan, particularly in arid and semi-arid regions where heat stress is a major challenge for crop production. This study aimed to assess the performance of different sorghum lines under heat stress conditions at the Arid Zone Research Centre, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. **Materials and Methods:** The experiment was conducted using a Randomized Complete Block Design (RCBD) having three replications. Ten sorghum lines/varieties were evaluated under heat stress, with key agronomic traits recorded, including plant height, days to 50% heading, leaf area index, leaves/plant, stem girth, maturity days, crop growth rate, grain count per head, head weight, 1000-grain weight, plant biomass, grain yield, and harvest index. Temperature fluctuations and heat stress indices were monitored throughout the study. Data were analyzed using Statistix 8.1 Software through ANOVA, and treatment means were compared using the LSD test at a 0.05 significance level. **Results:** Significant variation was observed among the sorghum lines. The sorghum line SS 97-2(S1), followed by the variety Dera Jowar, exhibited the highest agronomic and yield-related attributes, making them the most suitable for cultivation under heat-stressed agro-climatic conditions of the arid zone. **Conclusion:** The study provides valuable insights into the selection of heat-tolerant sorghum varieties, which can enhance productivity in arid and semi-arid regions. While the results indicate promising candidates for heat-stressed environments, further multi-location trials and molecular studies are recommended to validate findings and explore underlying genetic mechanisms for heat tolerance.

## KEYWORDS

Sorghum lines, heat stress, Dera Jowar, grain yield, arid zone



## INTRODUCTION

Given their sensitivity to changes in temperature, precipitation, and the frequency of natural disasters and occurrences, agricultural systems are particularly vulnerable to climate change. In the meantime, emissions from agriculture and automobiles play a significant role in global warming. Variations in the frequency and intensity of extreme weather events may have an impact on crop growth and development[1]. The two main components of climate change are higher yearly changes in temperature and rainfall[2].

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Overall, the effects of climate change have been evident for a while, but their far-reaching effects are now particularly evident in the agricultural sector, which is essential to the World's economy and food production[1,3]. To improve agricultural output, agronomic and genetic modifications are required[4]. In any agro-ecological zone, choosing the right crop variety is crucial to harvesting high-quality produce. Since different cultivars react differently to environmental conditions, it is crucial to find acceptable types of a crop that are compatible with the exposed agro-ecological conditions before introducing it into a new cropping system. Cultivating appropriate kinds based on the soil type, soil moisture, photoperiod, and temperature in a particular place might result in the maximum crop production[5]. In a climate change scenario, the primary constraint on heat and drought stress is the selection of indigenous cultivars that are suited for production in various agroecological circumstances. The end of the twenty-first century would see a 1.8-4.0°C increase in global surface temperature and a considerable change in global precipitation systems[6-8], which would have a major effect on water resources and agriculture[4,9]. Plant breeders are primarily concerned with yield decline over time and prioritize yield enhancement in conditions of moisture stress[2,10]. Major variables reducing crop development and production include drought, heat, cold, diseases, and pests[11-13]. Different environmental factors (such as soil moisture availability) that impact crop plant growth and interact with genotypes are linked to grain yield[14-16]. As the genetic mechanism responsible for drought control and grain yield under drought conditions is not fully explored[17-19], drought resistance in crops is one of the most complex traits to comprehend[4]. In many nations, this stress is a constant hindrance to agricultural output[18,20], and it can also occasionally result in agricultural production losses[21-23].

The studies were aimed at evaluating advanced sorghum lines for heat tolerance under the agro-ecological conditions of Dera Ismail Khan. Key physiological and yield-related traits will be assessed to determine heat stress resilience. The findings will aid in identifying heat-tolerant sorghum genotypes for sustainable cultivation.

## MATERIALS AND METHODS

**Experimental details and crop husbandry:** A field experiment was conducted at the Arid Zone Research Center (AZRC), Dera Ismail Khan, KPK, Pakistan, in 2018, using a Randomized Complete Block Design (RCBD) with three replications. The experiment aimed to determine heat stress on sorghum growth and yield under a changing climate. The soil was calcareous with insufficient organic matter, nitrogen, phosphorus, and potassium, making it prone to nutrient deficiencies. The region experiences high temperatures during the summer, with dry spells and storms exacerbating heat stress conditions. The annual rainfall ranges between 200-245 mm, and relative humidity varies from 52 to 79% between June and October.

High-quality seeds (germination >90%) of ten sorghum lines/varieties obtained from AZRC were sown in August, 2018 at a 10 kg/acre seed rate. The rows were spaced at 40 cm, with a plant-to-plant distance of 15 cm. Nutrient application was maintained at 60-60-40 kg NPK/ha at the time of sowing. The agronomic practices, like weeding and pest control, were uniformly applied across all treatments, and heat stress indices were considered in growth and yield analysis.

**Procedure to record agronomic parameters:** Five plants were randomly selected from each treatment for agronomic observations, and the average values were recorded. Plant height (cm) was measured from the base to the tip, while the total number of green leaves was manually counted. The time to 50% flowering (days) was recorded when half of the panicles had emerged from boot leaves. Maturity time (days) was assessed from sowing until the sorghum spikes changed color and grains hardened enough to break by hand. Stem girth (cm) was measured at three points (base, middle, and upper portion) using a measuring tape.

To incorporate heat stress analysis, leaf temperature and canopy temperature were measured using infrared thermometers at different growth stages.

**Procedure to record growth parameters:** At the time of flowering, three leaves were selected from each plant, and the area of each leaf was measured manually to compute the leaf area index by using formulae[24,25]:

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Ground area}}$$

The plants, grown in each subplot of the experiment, were removed from an area of a square meter after 30 and 60 days, and were subjected to drying in an oven at 105°C for a whole day and night. After that, the dry weight was calculated using an electric balance. The following formula was used to compute crop growth rate (g/$m^2$/day)[25,26]:

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1}$$

where, $W_1$ indicates the desiccated plant weight of 30 days, while $W_2$ is the desiccated plant weight of 60 days.

**Procedure to record yield and yield contributing parameters:** For calculating the weight of head, the central two rows were selected for ear head removal, and subsequent weighing was practiced after the heads were sun-dried and threshed. The grains so obtained were weighed at 15% moisture. In each treatment, five heads were chosen at random and sun dried, threshed, and the grains counted, with an average determined to estimate the number of grains per head. Following threshing, three thousand grain samples were gathered from each sub-plot and weighed on an electric scale to determine the weight of 1000 grains (g). Each sub-whole plot's head was removed from the plant, sundried, and threshed to obtain grains, which were then weighed to estimate the grain yield (kg/ha) using the following formulae[26]:

$$\text{GY} = \frac{\text{Weight of grains}}{\text{Total plot area (m-2)}} \times 10000$$

Fifteen plants uprooted from the central two rows were weighed through a spring balance in each treatment to analyze total biomass (kg/ha) production by using the following formula[27,28]:

$$\text{Biomass} = \frac{\text{Dry plant weight after harvest (kg)}}{\text{Total plot area (m)}} \times 10000$$

Harvest index (%) was calculated by using the formula given as under[29]:

$$\text{HI} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

**Statistical analysis:** The data was subjected to analysis of variance procedures, and the least significant difference (LSD = 0.05) test was used to distinguish the different treatment means. The data were analyzed using the computer software "Statistix 8.1" to estimate the significant effect of each treatment.

## RESULTS

**Variability of different sorghum lines based on agronomic attributes:** Agronomic parameters provide a crucial means to evaluate the adaptability of different sorghum lines under heat and drought stress conditions in arid regions. The results indicated significant variation in plant height, leaf count, time to 50% flowering, maturity period, and stem girth among the tested sorghum lines.

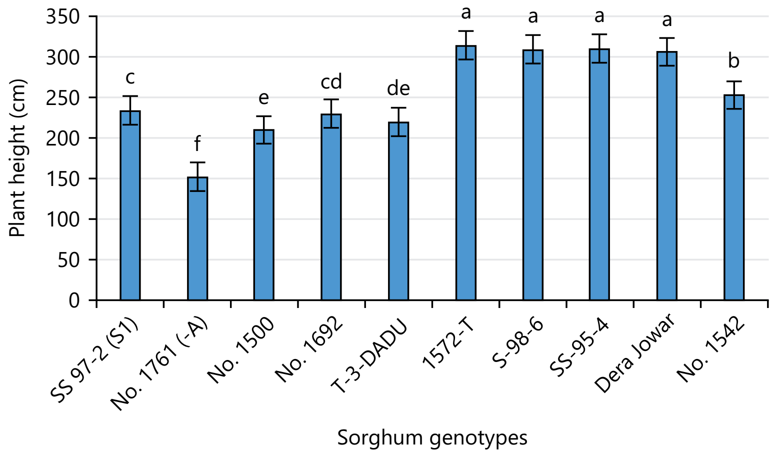


Fig. 1: Variability in plant height among different sorghum lines
Similar means in the Figure, accompanied by analogous letters, are declared as non-significant at 50% probability

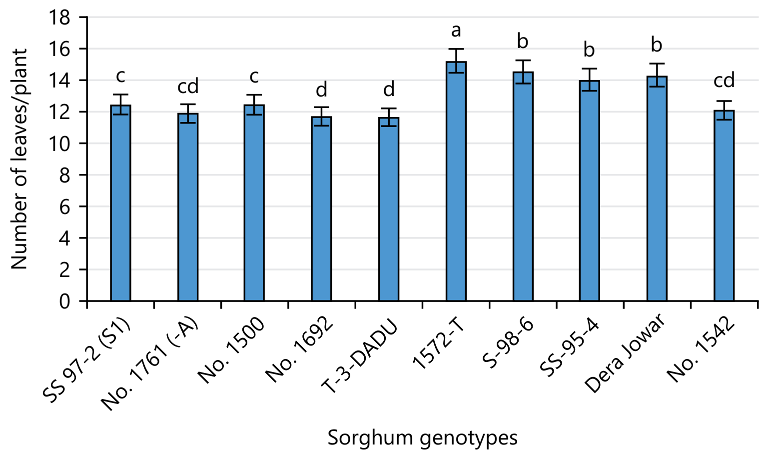


Fig. 2: Number of leaves per plant across different sorghum lines
Similar means in the Figure, accompanied by analogous letters, are declared as non-significant at 50% probability

Under heat and drought stress, taller plants generally indicate a better ability to access deeper soil moisture, enhancing drought tolerance. Sorghum line 1572-T exhibited the tallest plants, suggesting a potential advantage in moisture acquisition. SS-95-4 and S-98-6 also demonstrated promising plant height, whereas 1761 (-A) produced the shortest plants, indicating greater susceptibility to heat and drought stress (Fig. 1). Similarly, a higher number of leaves were observed in 1572-T, which may suggest better photosynthetic potential and resilience to heat stress. SS-98-6 and SS-95-4 also exhibited promising leaf production, while the lowest leaf count was recorded for T-3-DADU (Fig. 2).

The time to 50% flowering is crucial in heat stress conditions, as early flowering can help crops escape the most extreme temperatures. The longest time to 50% heading was observed in line 1692, indicating a prolonged vegetative phase, which may be detrimental under terminal heat stress. Conversely, SS-97-2 (S1) and 1761 (-A) exhibited early panicle emergence, which can be beneficial in avoiding high temperatures during reproductive growth. Similarly, delayed maturity was noted in 1692, while SS-97-2 (S1) reached maturity earlier than other lines, potentially avoiding terminal drought stress (Fig. 3).

Stem girth is an essential trait for structural stability and drought resilience. The maximum stem girth was observed in SS-97-2 (S1), followed by Dera Jowar and S-98-6, suggesting greater robustness under stress conditions. The minimum stem girth recorded in line 1500 indicates potential vulnerability to lodging under high winds and heat stress (Fig. 4).

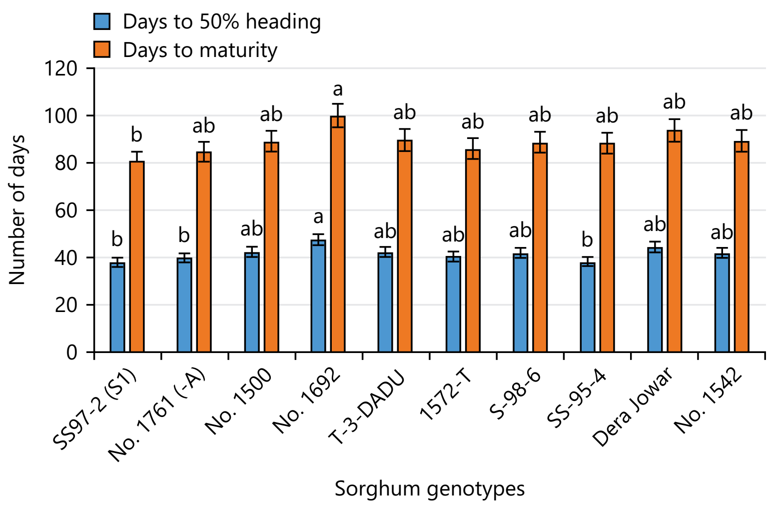


Fig. 3: Days to 50% heading and days to maturity for various sorghum lines

Similar means in the Figure, accompanied by analogous letters, are declared as non-significant at 50% probability

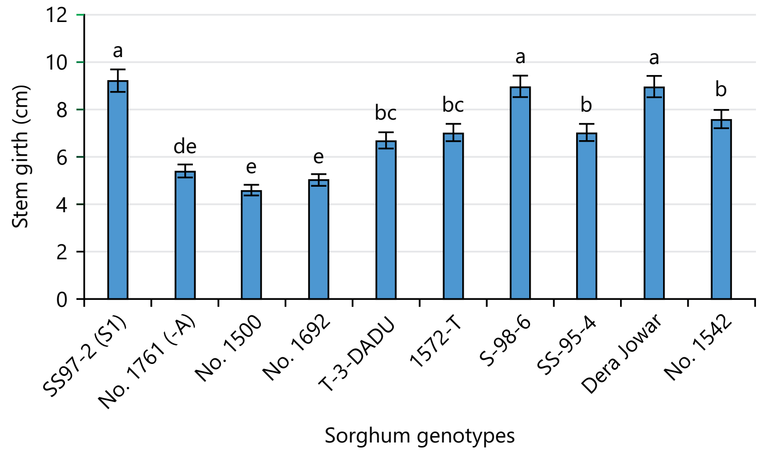


Fig. 4: Variation in stem girth among different sorghum lines

Similar means in the Figure, accompanied by analogous letters, are declared as non-significant at 50% probability

**Variability of different sorghum lines on the basis of growth attributes:** Growth parameters reflect the physiological response of different sorghum lines to environmental stress. The leaf area index (LAI) and crop growth rate (CGR) are critical for assessing the plant's ability to capture light energy for photosynthesis and sustain biomass production under heat and drought conditions.

The LAI was measured at the anthesis stage and varied significantly among the sorghum lines. The highest LAI was documented in SS-97-2 (S1), it was followed by the check variety and SS-95-4, indicating superior canopy development and greater capacity to intercept light for photosynthesis. In contrast, T-3-DADU exhibited the lowest LAI, followed by S-98-6, No. 1692, and 1572-T, which suggests reduced leaf expansion due to heat and water limitation (Fig. 5).

The CGR also varied significantly among sorghum lines, reflecting their adaptation to stress conditions. Maximum CGR was observed in the check variety (Dera Jowar), followed by SS-97-2 (S1), indicating better growth performance under elevated temperatures. However, T-3-DADU exhibited the lowest CGR, suggesting limited biomass accumulation under stress conditions (Fig. 6).

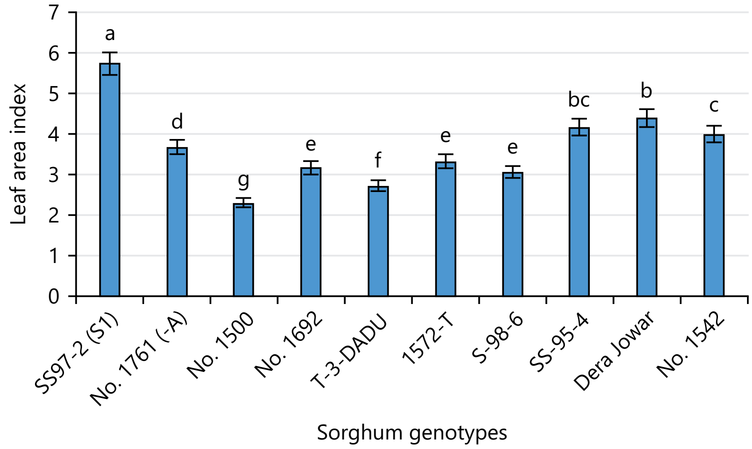


Fig. 5: Leaf area index comparison across sorghum lines

Similar means in the Figure, accompanied by analogous letters, are declared as non-significant at 50% probability

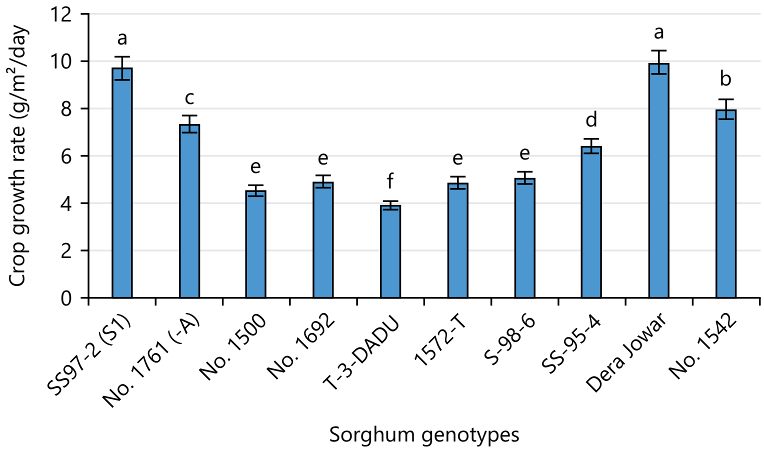


Fig. 6: Crop growth rate variability among sorghum lines

Similar means in the Figure, accompanied by analogous letters, are declared as non-significant at 50% probability

Table 1: Variability of different sorghum lines based on yield and yield contributing parameters

| Treatment | HW (g) | GPH | TGW (g) | GY (kg/ha) | BM (kg/ha) | HI (%) |
|---|---|---|---|---|---|---|
| $T_1$ | 32.50$^{a}$ | 1386.0$^{a}$ | 23.460$^{a}$ | 3390.3$^{a}$ | 20131$^{a}$ | 16.89$^{ab}$ |
| $T_2$ | 15.07$^{e}$ | 875.7$^{d}$ | 17.237$^{d}$ | 2376.7$^{d}$ | 17078$^{bc}$ | 14.02$^{d}$ |
| $T_3$ | 4.20$^{i}$ | 360.0$^{g}$ | 11.657$^{g}$ | 429.7$^{h}$ | 13806$^{ef}$ | 3.08$^{f}$ |
| $T_4$ | 7.83$^{h}$ | 589.3$^{f}$ | 13.263$^{fg}$ | 2064.3$^{e}$ | 14122$^{def}$ | 14.65$^{cd}$ |
| $T_5$ | 5.30$^{i}$ | 372.7$^{g}$ | 14.220$^{ef}$ | 646.0$^{g}$ | 13359$^{f}$ | 4.78$^{f}$ |
| $T_6$ | 11.53$^{f}$ | 749.0$^{e}$ | 15.397$^{e}$ | 2263.3$^{d}$ | 15442$^{cde}$ | 14.66$^{cd}$ |
| $T_7$ | 9.91$^{g}$ | 626.7$^{f}$ | 15.843$^{de}$ | 1013.7$^{f}$ | 13229$^{f}$ | 7.75$^{e}$ |
| $T_8$ | 20.58$^{d}$ | 1074.3$^{c}$ | 19.177$^{c}$ | 2756.0$^{c}$ | 15876$^{bcd}$ | 17.42$^{a}$ |
| $T_9$ | 29.36$^{b}$ | 1359.0$^{a}$ | 21.627$^{b}$ | 2955.0$^{b}$ | 19513$^{a}$ | 15.20$^{bcd}$ |
| $T_{10}$ | 27.32$^{c}$ | 1299.7$^{b}$ | 21.027$^{b}$ | 2872.7$^{bc}$ | 17522$^{b}$ | 16.41$^{abc}$ |

Variability of different sorghum lines based on yield and yield contributing parameters. T: Treatment, $T_1$: SS 97-2, $T_2$: No. 1761 (-A), $T_3$: No. 1500, $T_4$: No.1692, $T_5$: T-3-DADU, $T_6$: 1572-T, $T_7$: S-98-6, $T_8$: SS-95-4, $T_9$: Dera Jowar, $T_{10}$: No. 1542. HW: Head weight, GPH: Grain per head, TGW: Thousand grain weight, GY: Grain yield, HI: Harvest index, BM: Biomass, Similar means portrayed in the table, accompanied by analogous letters, are declared non-significant at 5% level of probability

**Variability of sorghum lines on the basis of yield and yield-contributing parameters:** Yield-contributing parameters are essential in selecting stress-tolerant lines for sustainable grain production under heat and drought stress. The analysis showed significant differences in head weight, number of grains/head, thousand-grain weight, grain yield, biomass, and harvest index (HI) among the sorghum lines.

The highest head weight was observed in SS-97-2 (S1), followed by the check variety, whereas the lowest head weight was recorded for lines 1500 and T-3-DADU (Table 1). This suggests that SS-97-2 (S1) and Dera Jowar are more resilient to heat stress, maintaining head development despite adverse conditions.

The number of grains/head, thousand grain weight, and grain yield (kg/ha) were highest in SS-97-2 (S1), followed closely by the check variety, indicating their superior reproductive success under high temperatures. Line 1500 recorded the lowest grain number, highlighting its sensitivity to heat stress. Maximum biomass was observed in SS-97-2 (20131 kg/ha) and the check variety (19513 kg/ha), followed by lines 1542 and 1761 (-A). Conversely, S-98-6 recorded the lowest biomass (13359 kg/ha), indicating its lower adaptability to stress conditions.

Interestingly, the highest H.I. was recorded in T-3-DADU and S-98-4, followed by the check varieties 1572-T and 1692. However, the lowest HI was also observed in T-3-DADU and S-98-4 (Table 1), suggesting inconsistencies in their ability to partition biomass into grain yield.

## DISCUSSION

The successful production of the crop is based on the performance triangle of genetics, environment, and physiology. The enhancement of economic return, even under suboptimal environments, through genetic improvements remains the primary focus of producers and breeders. El Naim *et al.*[30] documented that profound differences were seen in yield, height, and maturity under variegated environmental conditions. Similarly, Rocateli *et al.*[31] uncovered that sorghum cultivars provided maximum economic returns when exhibiting stable performance in specific agricultural conditions. In this study, the different sorghum lines exhibited variation in plant height, which may be due to their genetic background and environmental adaptability, particularly to heat and drought stress. Ashraf[32] and Fahad *et al.*[33] also supported the findings that variations in different sorghum lines are based on their hereditary traits and local adaptability. Besides plant height variation, the genetic variability among the sorghum lines also exhibited differences in the number of leaves[34]. The genotype SS 97-2 (S1) demonstrated strong resistance to arid conditions, maximizing its genetic potential to produce a higher number of leaves despite heat stress. Chughtai *et al.*[35] and Awori *et al.*[36] reported a prominent difference in leaf count per plant, stating that variations in genetic makeup led to significant disparities in the number of leaves per plant. The number of days to 50% flowering varies significantly between sorghum cultivars, a factor influenced by temperature stress[11]. Similarly, Meki *et al.*[37] observed significant variability in days to 50% heading among several sorghum lines.

The time to maturity of a plant determines its life span, indicating whether the genotype is long or short in duration. However, climate and environmental factors, particularly heat stress, can accelerate or delay maturity. If environmental variation is not a limiting factor, the line that achieved 50% blooming in the shortest time also exhibited quicker physiological development than other genotypes. Our findings align with those of Udayashankara *et al.*[1], who found that EDO inbred lines matured earlier than commercial checks. The study also revealed that lines SS 97-2 (S1), Dera Jowar (check variety), and S-98-6 had the thickest stem girth, which can be attributed to genetic potential and higher nutrient absorption capabilities, allowing for thicker stems even under drought and heat stress[38,39].

The leaf area index (LAI) of the highest-yielding cultivars was relatively high, demonstrating that they efficiently utilized available light and water resources to maximize grain production[40]. The highest crop growth rate (CGR) observed in certain lines may be attributed to their genetic potential and environmental adaptability. Current findings are comparable to those of Gavuzzi *et al.*[41], who found that crop growth rate was strongly associated with higher dry matter accumulation under variable climatic conditions. The ability of a sorghum line to sustain biomass production under heat and drought stress is indicative of its tolerance mechanisms. The highest head weight observed in some genotypes suggests that they maintained efficient photosynthetic activity and effective assimilate partitioning, leading to enhanced grain filling. Other studies by Crespo-Herrera *et al.*[42] and Shafi *et al.*[43] observed similar findings, reporting a significant correlation between head weight and sorghum grain yield. Furthermore, the photosynthetic efficiency of some lines resulted in heavier grains, highlighting their ability to transport more assimilates from source to sink under heat stress conditions[44].

The lower grain yields recorded in lines No. 1500 and T-3-DADU indicate a weaker genetic constitution and reduced photosynthetic efficiency, as these lines struggled to convert assimilates into economic yield (grain yield). Head length, 1000-grain weight, and fertility percentage are critical yield-contributing factors, as highlighted by another study[45]. According to Abreha *et al.*[46], yield variation among sorghum genotypes may be influenced by multiple factors, including soil nutrient availability and water uptake efficiency, both of which are crucial under heat and drought stress. The highest biomass production observed in SS 97-2 (S1) and the check variety suggests that these lines exhibited superior physiological traits and resilience to environmental stress[25]. Moreover, the highest harvest index (HI) observed in T-3-DADU and S-98-4 indicates their efficiency in partitioning biomass toward grain production, a crucial trait for heat and drought tolerance[39].

In terms of overall yield performance, genotypic variability played a crucial role in determining the adaptability of different sorghum lines to heat and drought stress. Another study of Bello *et al.*[34] identified promising genotypes based on traits such as panicle length, leaf area, and earliness, which are also critical factors for drought resilience. Previous studies observed 20-25% yield variations between local and advanced cultivars, emphasizing the role of genetic improvement in enhancing stress tolerance[47-50]. Fischer and Edmeades[51] also documented significant genetic variability among sorghum cultivars, highlighting the potential for breeding heat and drought-tolerant varieties. Traits such as dry fodder yield, stem girth, and panicle length exhibited high heritability, supporting the findings of this study that these parameters contribute to sorghum resilience under stress conditions. Similarly, Adetokunbo *et al.*[5] found that planting date adjustments under variable environments significantly impacted plant attributes, further supporting the role of environmental adaptation in sorghum performance. Vasilakoglou *et al.*[52] demonstrated significant genotypic and phenotypic variations in panicle length, grains per panicle, and plant height, all of which contribute to drought and heat tolerance. Other studies concluded that environmental factors have the most significant impact on sorghum performance, with genetic factors also playing a role[39,45,46]. Abreha *et al.*[46] reported considerable variation in sorghum genotypes regarding agronomic traits, indicating that different cultivars exhibit varied responses to environmental stressors.

Overall, this study highlights the importance of genetic variation in determining the resilience of sorghum lines to heat and drought stress. The findings emphasize the need for targeted breeding programs to develop sorghum cultivars that can withstand extreme climatic conditions while maintaining high yield potential.

## CONCLUSION

This study evaluated the performance of different sorghum lines under heat and drought stress conditions in an arid environment. Significant variability was observed in agronomic, growth, and yield-related traits among the tested lines. SS-97-2 (S1) and the check variety, Dera Jowar, exhibited superior adaptability, higher biomass production, and enhanced grain yield, making them the most suitable candidates for cultivation in heat-stressed regions. Traits such as early flowering, higher leaf area index, and robust stem girth were found to be crucial for heat tolerance and productivity. The findings highlight the importance of selecting resilient genotypes to mitigate the adverse effects of climate change on sorghum production. Future research should focus on the genetic mechanisms underlying heat and drought tolerance and explore breeding strategies to develop climate-resilient sorghum varieties. Additionally, integrating molecular and physiological approaches can further enhance selection efficiency and improve crop sustainability under extreme climatic conditions.

## SIGNIFICANCE STATEMENT

This study discovered the potential of SS-97-2 (S1) and Dera Jowar as heat and drought-tolerant sorghum varieties that can be beneficial for improving crop resilience and productivity in arid and semi-arid regions. The outcomes of this study will help to discover the critical areas of genotype-environment interactions and stress adaptation mechanisms that are not fully explored. Thus, a new theory on climate-resilient sorghum breeding may be arrived at.

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