

Evaluation of heat tolerance in cowpea genotypes for sustained productivity under high temperatures

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Received: 29 January 2025

Revised: 28 March 2025

Accepted: 28 May 2025

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Abstract

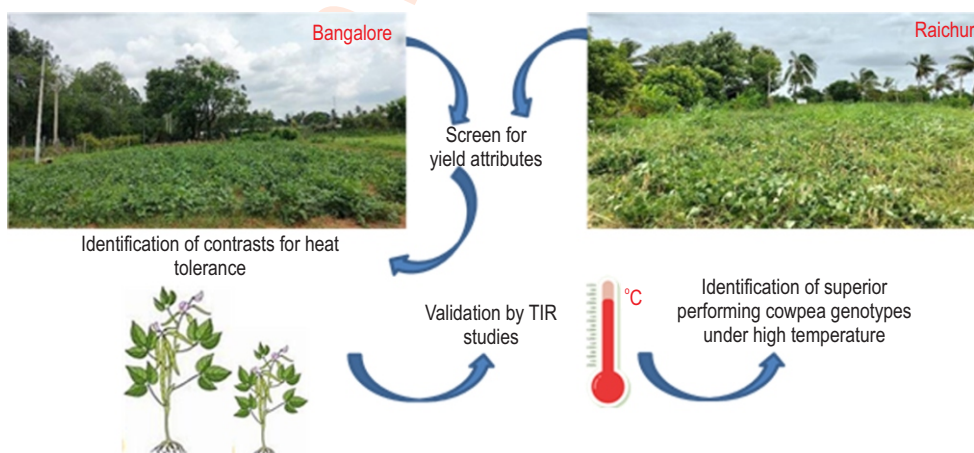
Aim: The study aimed to evaluate heat tolerance in cowpea genotypes under high-temperature and identify thermotolerant genotypes that can sustain productivity in environments with temperatures exceeding 35°C.

Methodology: A total of 191 cowpea genotypes were screened for yield attributes at two locations, Bangalore and Raichur, which differed in temperature exposure. Heat stress effects on different physiological traits were measured and contrasting genotypes were further assessed using the temperature induction response (TIR) approach.

Results: Significant reductions in total dry matter and yield traits were observed at high-temperature location, Raichur. However, heat-tolerant genotypes exhibited minimal reduction in total dry matter and root length. Ten genotypes, including IC-402172, EC-458453 and NBC-21, demonstrated consistent thermotolerance at both field and cellular levels.

Interpretation: The study identified specific cowpea genotypes that can tolerate high temperatures up to 35°C without significant loss in productivity, providing valuable candidates for crop improvement.

Key words: Cow pea, Heat stress, Temperature induction response, Thermotolerance



Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.], a vital legume of African origin, is an important crop of semi-arid tropical regions (Timko *et al.*, 2008). It is widely cultivated across tropical and subtropical zones (Tambitkar *et al.*, 2020). Cowpea is primarily grown both for food and fodder under rain-fed conditions, often facing intermittent moisture stress. It is generally cultivated during monsoon season, either as a cover crop or in mixed farming with cereals, and also during summer under irrigated conditions, where high temperatures often prevail (Nevhuladzi *et al.*, 2020). Despite its adaptability, temperatures above 35°C during day and above 20°C at night can severely impact yield by reducing pod formation (Turk *et al.*, 1980). With global warming, the rising temperatures pose an even greater threat, potentially reducing crop productivity by 15-35% (Ortiz *et al.*, 2008). Heat stress has become a major abiotic factor affecting plants at cellular level. It damages protein and triggers oxidative stress by generating reactive oxygen species (ROS), leading to cellular injury (Mittler, 2006; Tambitkar *et al.*, 2020). Photosynthesis and antioxidant enzyme activities are also impaired under high temperatures, further hampering plant growth (Bitá and Gerats, 2013; Noctor and Foyer, 1998).

Seedling vigor, which is essential for early growth and survival of cowpea under field conditions, is also adversely affected by high temperatures. Seedlings exposed to temperatures above the optimal range often show stunted growth, reduced root elongation, and poor shoot development. The damage to root systems hampers the ability of seedling to uptake water and nutrients, further limiting growth (Nevhuladzi *et al.*, 2020). The germination process is particularly sensitive to temperature fluctuations, with the optimal range for cowpea germination typically between 25°C and 35°C. When temperatures exceed 40°C, the germination rate drops significantly. High temperatures can impair seed coat integrity, disrupt water uptake during imbibition, and inhibit the enzymatic activities required for metabolic activation. As a result, seed germination can be delayed or reduced, leading to poor seedling establishment (Tambitkar *et al.*, 2020). In cowpea, elevated night temperatures critically reduce yield, emphasizing the need to identify genotypes with greater resilience to heat (Jarvis *et al.*, 2011).

High temperatures, particularly during flowering stage, leads to flower drop, which in turn reduces the number of pods and negatively impact pod quality by decreasing their size and pod weight (Tambitkar *et al.*, 2020). Biochemically, heat stress triggers a variety of responses within cowpea plants. One of the most important biochemical mechanisms is the upregulation of heat shock proteins (HSPs). These proteins help maintain cellular integrity and ensure that essential metabolic processes continue under stress conditions. However, the accumulation of reactive oxygen species (ROS) due to high temperatures can also cause oxidative damage to cellular components, such as proteins, lipids, and DNA. This results in the overall reduction in yield and crop productivity (Puppala *et al.*, 2023). In addition, the impact of high temperature on partitioning of assimilates from source to sink results in a reduction in pod yield (Akbar *et al.*, 2017).

These environmental stress factors highlight the urgent need to identify and develop heat-tolerant cowpea genotypes. Such advancements could significantly enhance the crop's resilience to climate change, ensuring sustained productivity in regions where cowpea is a staple crop for food security and economic stability (Toscano *et al.*, 2019). To combat this, cowpea plants enhance their antioxidant defense mechanisms, including the production of enzymes like superoxide dismutase, catalase and peroxidases, which help neutralize ROS and reduce oxidative stress (Reshma *et al.*, 2021).

To address declining cowpea productivity under heat stress from climate change, developing thermotolerant varieties is crucial for food security. The field screening and temperature induction response (TIR) method can effectively screen for genotypes by simulating gradual temperature stress, enabling early identification of heat-tolerant genotypes through sub-lethal stress exposure that triggers acclimation responses in seedlings (Akbar *et al.*, 2017; Bitá and Gerats, 2013). TIR is effective and highly reliable method commonly used to screen genotypes at seedling stage (Reshma *et al.*, 2021), because seedling tolerance is an important factor for crop establishment, especially in semi-arid areas where soil temperatures are high (Chaudhary *et al.*, 2020). Moreover, the TIR method allows for the identification of genotypes with superior thermo tolerance, which can be crucial in ensuring consistent yields under increasingly erratic climatic conditions (Nevhuladzi *et al.*, 2020).

By incorporating these genotypes into breeding programs, it is possible to develop cowpea varieties that maintain productivity and contribute to food security in regions vulnerable to heat stress. Furthermore, understanding the physiological mechanisms underlying heat tolerance can facilitate the development of molecular markers for more efficient selection in breeding programs (Toscano *et al.*, 2019). In view of the above this study was carried out to assess genetic diversity among cowpea genotypes for heat tolerance, utilizing both field evaluation and the TIR method to identify genotypes that perform well under high-temperature conditions.

Materials and Methods

Experimental details: The 191 genotypes of cowpea were used in the field screening for high temperature tolerance at two locations; Raichur district (15°45' N, 76°35' E, 1335 m altitude) (Adarsh *et al.*, 2024) and Bangalore (12°58' N, 77°35' E, 930 m altitude). The seeds were procured from the All India Coordinated Pulses Improvement Project, GKVK, Bangalore. Seeds were obtained from the AICRP, GKVK, Bangalore. The field was prepared by plowing, harrowing and leveling. Ten seeds per genotype were sown at 45 cm spacing, with 60 cm between rows. Single plants per hill were maintained, and manual weeding was done twice within 35 days of sowing. At both locations, blocking was done based on soil heterogeneity and field gradients to minimize variability. Additionally, repeated check varieties were included across blocks to assess and adjust for spatial variability. During the experimental period at Bangalore the maximum

temperature (T_{max}) was 30.9 °C and minimum temperature (T_{min}) was 19.6 °C with an average rainfall of 5.5 mm. Similarly, at Raichur T_{max} of 38 °C and T_{min} of 23.4 °C was recorded with average rainfall of 1.1 mm (Fig. 1).

Physio-morphological and yield traits: At both Raichur and Bangalore locations, leaf temperature and SPAD chlorophyll meter readings (SCMR) were taken at the reproductive stage. Leaf temperature was measured using an infrared thermometer (Model: MT4, Raytek, USA) held at 15 cm distance from the top third leaf. SCMR was measured using a SPAD Chlorophyll meter (Model: SPAD-502, Minolta Camera Co. Ltd., Osaka, Japan). The fully expanded third leaf from the top was used for estimating chlorophyll content (Barros *et al.*, 2021). During harvest, plant height was measured from the base to the tip of the main tiller. The number of branches, number of pods, pod length, seeds per pod, pod weight, seed yield and total dry matter were recorded in four randomly selected plants of each cowpea genotype.

Assessment of contrast selection and genetic diversity by temperature induction response (TIR) method: Ten

germplasm lines showing the smallest difference in total dry matter (TDM) between the two experiments were classified as tolerant. The accessions categorized as tolerant included: IC-402172, EC-458453, EC-458470, NBC-21, NBC-14, EC-394708, CB-10, IC-458430, IC-249588, and EC-458490. In contrast, the germplasm lines with largest difference in TDM were identified as susceptible. The accessions categorized as sensitive included: NBC-47, CP-98, C-152, IC-402114, EC-458480, EC-458440, IC-253251, 97767(10), VC-458492 and EC-458483. A temperature induction response (TIR) method was employed to evaluate 20 cowpea genotypes, each with three replications, selected based on contrasting heat tolerance traits identified from variations in total dry matter (TDM) (Srikanthbabu *et al.*, 2002).

TIR protocol was standardized using cowpea cultivar KBC-9. KBC-9 is known for its robust growth and resilience to stress, making it an ideal candidate for developing and testing protocols aimed at identifying heat-tolerant genotypes (Srikanthbabu *et al.*, 2002). For identification of lethal temperatures, 18-hr-old seedlings were used. One set of seedlings were exposed to lethal temperatures (50°C, 51°C and

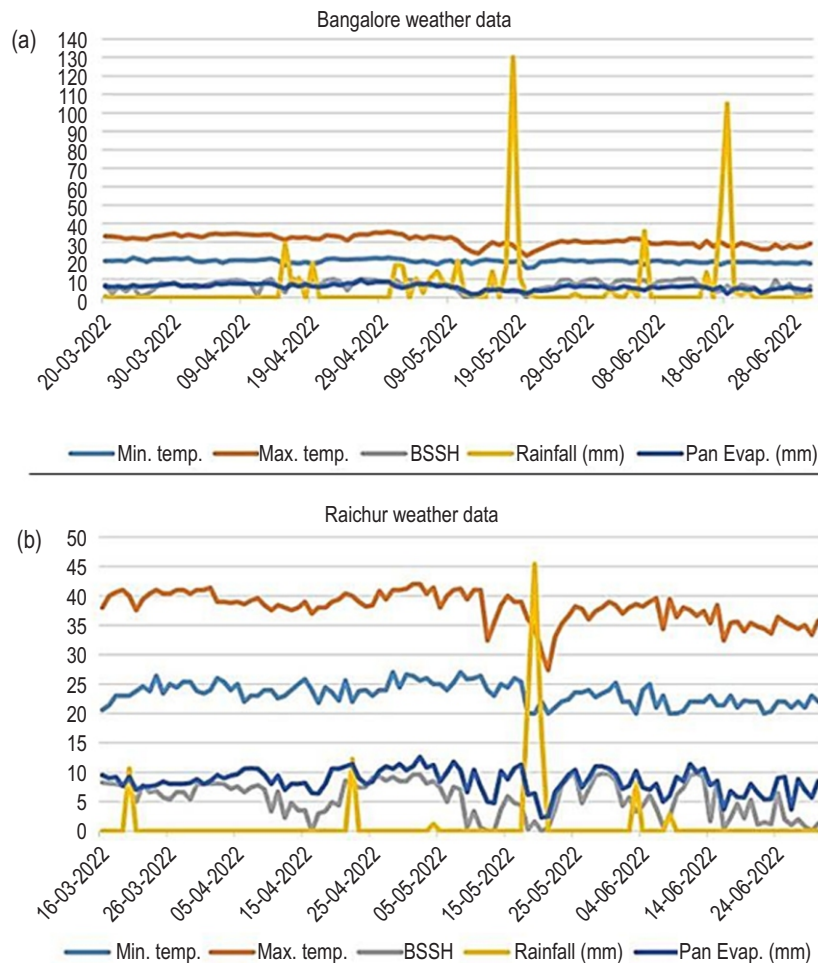


Fig. 1: Climate data throughout growing season to visualize temperature fluctuations between (a) Bangalore and (b) Raichur locations.

52°C) at 70% relative humidity. The exposure duration was 1, 2, and 3 hrs. For each lethal temperature, three different exposure durations were tested. Another set of seedlings was maintained under control conditions at 28°C and 70% RH. This group served as a baseline for comparison to assess the effects of heat stress. Post heat stress treatment (or the control period), all seedlings were subjected to a recovery period of 72 hr (Sapna et al., 2014).

Identification of induction temperature: For the induction process, 18 hr old seedlings were exposed to sub-lethal temperatures (28–52°C) for 2.5, 5 and 7.5 hr, at 70% relative humidity. After 72 hr recovery, the shoot and root lengths were measured to assess survival and growth (Srikanthbabu et al., 2002; Sapna et al., 2014).

Screening contrasting for genotypes using TIR: Seedlings from contrasting cowpea genotypes were grown in Petri dishes for 18 hr and uniform seedlings with 0.5 cm root length were transferred to aluminum trays. Three treatments were applied: control, induction (gradual increase from 28°C to 52°C over 5 hr) and lethal (direct exposure to 52°C for 3 hr). Post treatment, trays were watered and placed at room temperature for 72 hr for seedling recovery. Each treatment had three replicates with 10 seedlings per replicate. TIR experiment for contrasting genotypes was analyzed using a completely randomized design (Srikanthbabu et al., 2002).

Estimation seedling survival: After recovery period of 72 hr, the number of dead seedlings (ungerminated) were counted in all three treatments and used for calculating of percent seedling mortality and survival as mentioned by Srikanthbabu et al. (2002).

Measuring seedling growth: After the recovery period, the survived seedlings were used for taking root and shoot length using a measuring scale (cm) in induction and control treatments and percent reduction in recovery growth (% RRG) for root and shoot were computed (Srikanthbabu et al., 2002). From this experiment, 10 top performing genotypes both in terms of seedling survival and higher recovery growth were termed as tolerant and 10 lowest ranking for same parameters as sensitive.

Statistical Analysis: Experimental data obtained from Bangalore and Raichur experiments were analyzed using the augmented RCBD model in R-Studio (agricolae package) to assess the effects of different treatments. The analysis was complemented by generating a butterfly plot and principal component analysis (PCA) using SR plot.

Results and Discussion

The performance of 191 cowpea genotypes varied significantly between Bangalore and Raichur, study site reflecting the contrasting environmental conditions, particularly in relation to heat stress. Plants in Bangalore exhibited greater height (mean: 54.00 cm) compared to those in Raichur (44.33 cm), suggesting a more favorable growth environment. The maximum plant height in Bangalore observed was 73.79 cm versus 67.24

cm in Raichur, highlighting a greater growth potential under relatively optimal conditions. Similarly, the number of branches per plant was higher in Bangalore (6.61) than in Raichur (4.84), though both locations showed wide ranges, indicating considerable genotypic variability and adaptability for this trait (Table 1).

Conducting the experiment across two locations allowed for a robust assessment of genotype stability under varying temperature conditions. This approach provided insights into the adaptability of genotypes, especially in terms of yield traits under heat stress. The use of an augmented RCBD model further strengthened the analysis by effectively managing variability within and between experimental sites. Physiologically, the SPAD Chlorophyll Meter Reading (SCMR), a proxy for photosynthetic efficiency was higher in Bangalore (51.97) than in Raichur (48.30), suggesting better photosynthetic performance under less stressful conditions (Adarsh et al., 2024). Leaf temperature data further highlighted the difference in environmental stress: Bangalore showed a mean of 29.02°C, whereas Raichur recorded a higher mean of 36.16°C. Notably, IC-402172 maintained the lowest leaf temperature (30.33°C) in Raichur, indicating a potential heat avoidance mechanism, such as improved transpirational cooling. This ability of genotypes to regulate leaf temperature may reduce the risk of chlorophyll degradation under heat stress (Toscano et al., 2019).

While higher SPAD values often reflect increased chlorophyll content, they can also result from structural factors like leaf thickness or mesophyll density (Adarsh et al., 2024). Therefore, additional studies such as direct chlorophyll extraction and anatomical analysis are necessary to fully understand the underlying mechanisms of thermotolerance. Reproductive traits also demonstrated marked differences between the two locations. Seed weight was higher in Bangalore (65.20 g per plant) than in Raichur (56.23 g per plant), reflecting better reproductive success in cooler conditions. Genotypes such as EC-472267 and CPD-15 showed in particular greater seed weights in Bangalore. Other yield components, including pod length (17.06 cm vs. 15.78 cm), seeds per pod (14.92 vs. 13.58) and pods per plant (44.35 vs. 37.62) were also comparatively superior in Bangalore in comparison to Raichur (Table 1). These results suggest that plants exposed to lesser heat stress can allocate more resources toward reproductive development (Deva et al., 2020).

Shoot dry weight (64.51 g per plant in Bangalore vs. 50.10 g per plant in Raichur) and pod yield (85.53 g per plant vs. 71.23 g per plant) further reinforce the advantage of Bangalore environment. The butterfly plot (Fig. 2) illustrated genotype-specific responses, with traits such as shoot dry weight, SCMR and total dry matter contributing most to observed variation. They act as key indicators of adaptability under heat stress (Toscano et al., 2019). Total dry matter (TDM) was higher in Bangalore (150.04 g per plant) than in Raichur (121.33 g per plant), demonstrating an overall superior biomass accumulation in cooler conditions (Alexieva et al., 2001). The difference of 28.71 g per plant in TDM between locations underscore the impact of heat stress on growth (Nevhulauzi et al., 2020). Certain genotypes, including IC-202777 and NBC-36,

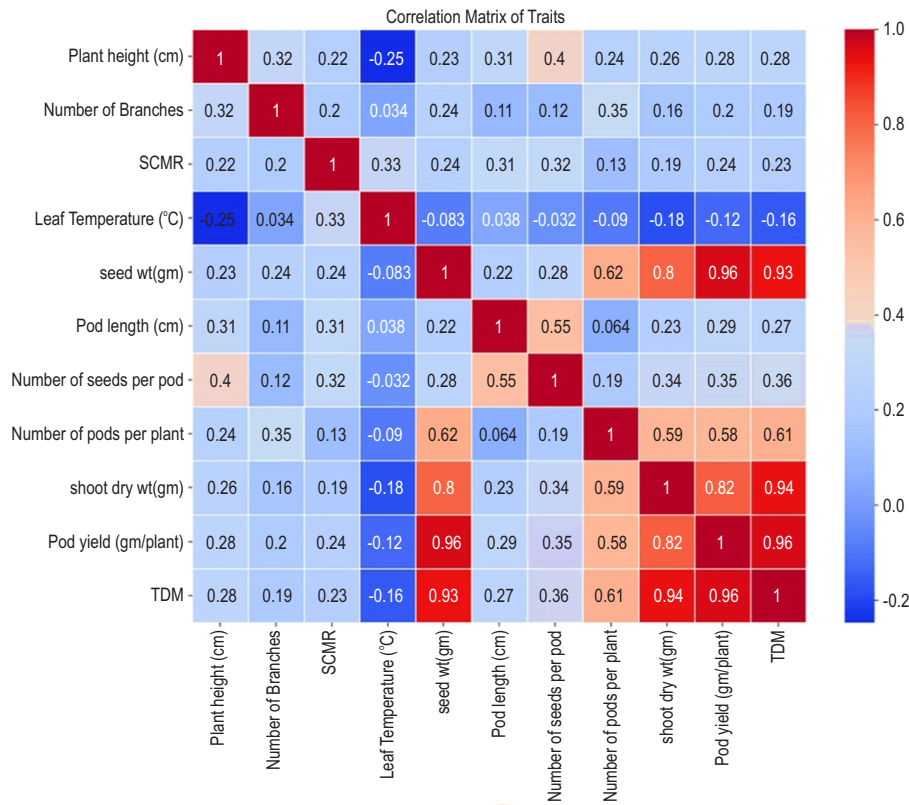


Fig. 3: Principle component analysis (PCA) and heat map showing correlation between the physio-morphological traits of cowpea grown in Raichur.

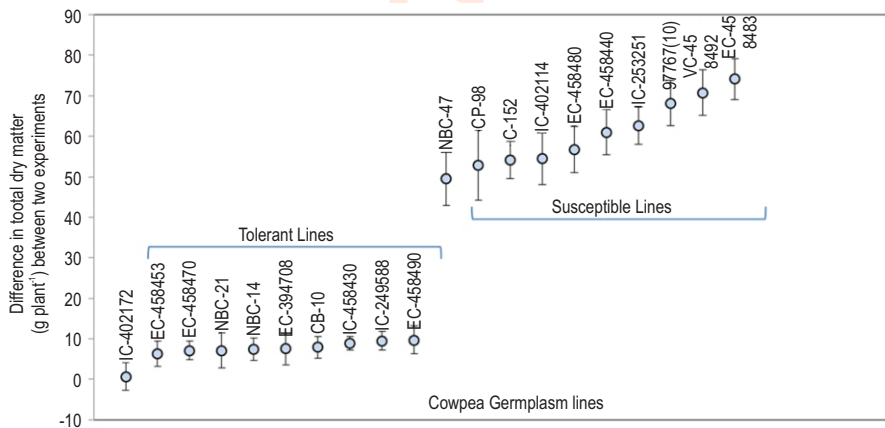


Fig. 4: Difference in the total dry matter between two experiments in the contrasts.

environmental factors in shaping crop performance and supports the need for multi-location trials (Rani *et al.*, 2024). Cohen's d effect sizes further confirmed these differences: values above 0.8 for several traits indicate large effects, with leaf temperature showing a specifically strong negative effect (-3.64), pointing to significantly higher heat stress in Raichur. Other traits such as

PH, SCMR, SDW and NOB also showed large effects, reinforcing their importance in differentiating genotype responses under stress (Table 1). In conclusion, cowpea genotypes performed better in Bangalore's favorable conditions comparatively. However, the broad range of responses observed across both locations highlights the presence of genotypes with high

Table 1: Variation in physio-morphological traits in 191 cowpea genotypes grown in Bangalore and Raichur for screening for thermotolerance. PH: Plant height, NOB: Number of Branches, SCMR: SPAD chlorophyll meter reading, LT: Leaf Temperature, SW: Seed weight, PL: Pod length, NSPP: Number of seeds per pod, NPPP: Number of pods per plant, SDW: Shoot dry weight, PY: Pod yield, TDM: Total dry matter, Ban: Bangalore, Rai: Raichur

	PH (cm)		NOB		SCMR		LT (°C)		SW (g plant ⁻¹)		PL (cm)		NSPP		NPPP		SDW (g plant ⁻¹)		PY (g plant ⁻¹)		TDM (g plant ⁻¹)	
	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai	Ban	Rai
Mean	54.00	44.33	6.61	4.84	51.97	48.30	29.02	36.15	65.20	56.23	17.06	15.78	14.92	13.58	44.35	37.62	64.51	50.10	85.53	71.23	150.04	121.33
Min	34.12	25.28	1.00	1.00	42.11	39.11	17.78	30.33	21.33	25.02	11.49	9.82	10.78	10.00	18.67	16.67	31.83	21.83	36.33	40.02	74.94	65.03
Max	73.79	67.24	11.18	8.65	59.92	55.92	33.67	42.33	117.52	116.90	26.90	23.85	18.33	17.21	83.67	62.33	98.33	79.47	138.28	131.90	235.83	183.29
SD	7.97	7.72	1.79	1.60	3.60	3.29	1.64	2.23	20.16	16.61	2.20	2.09	1.55	1.55	14.78	10.19	15.62	13.00	22.58	16.61	36.41	27.52
C.V.	5.93	5.93	7.93	7.45	5.93	5.94	5.93	5.99	6.33	6.27	5.96	5.94	6.20	6.41	6.48	6.30	6.15	6.17	6.21	6.15	6.16	6.13
S.E.	1.85	1.52	0.30	0.21	1.78	1.66	0.99	1.25	2.39	2.04	0.59	0.54	0.53	0.50	1.66	1.37	2.29	1.78	3.07	2.53	5.34	4.30
C.D. 5%	5.14	4.22	0.84	0.58	4.95	4.60	2.76	3.48	6.64	5.66	1.63	1.50	1.49	1.40	4.61	3.80	6.37	4.96	8.52	7.04	14.85	11.95
C.D. 1%	6.76	5.56	1.11	0.76	6.51	6.06	3.64	4.58	8.75	7.45	2.15	1.98	1.96	1.84	6.07	5.01	8.39	6.53	11.22	9.27	19.55	15.73
Range Lowest	34.10	25.30	0.00	0.00	42.10	39.10	17.67	30.33	21.33	25.02	11.50	9.80	10.67	10.00	19.00	17.00	31.83	21.83	36.33	40.02	74.94	65.03
Range Highest	73.80	67.23	11.00	8.67	59.90	55.90	33.67	42.33	143.00	116.90	26.90	23.83	18.00	17.33	84.00	62.00	98.33	79.47	138.28	131.90	235.83	183.29
Effect size (Cohen's d)	1.23 (Large)	1.04 (Large)	1.06 (Large)	1.06 (Large)	1.06 (Large)	1.06 (Large)	-3.64 (Very Large, Raichur higher)	3.64 (Very Large, Raichur higher)	0.49 (Medium)	0.49 (Medium)	0.60 (Medium)	0.86 (Large)	0.86 (Large)	0.53 (Medium)	0.53 (Medium)	1.00 (Large)	1.00 (Large)	0.72 (Medium to Large)	0.72 (Medium to Large)	0.89 (Large)	0.89 (Large)	0.89 (Large)

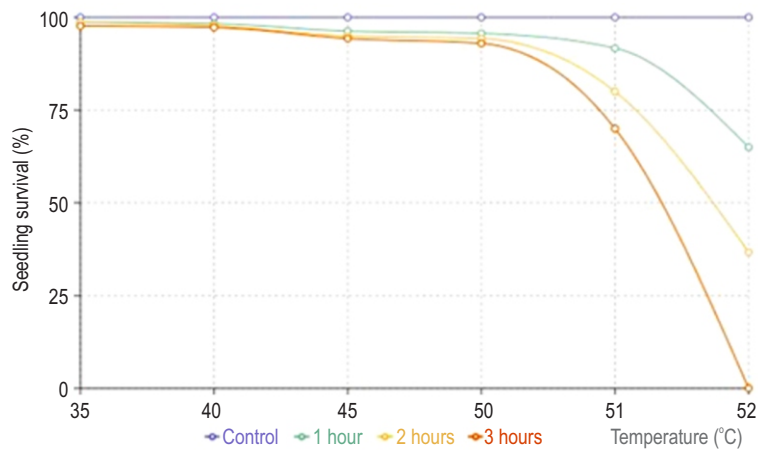


Fig. 5: Seedling survival at different temperatures and durations.

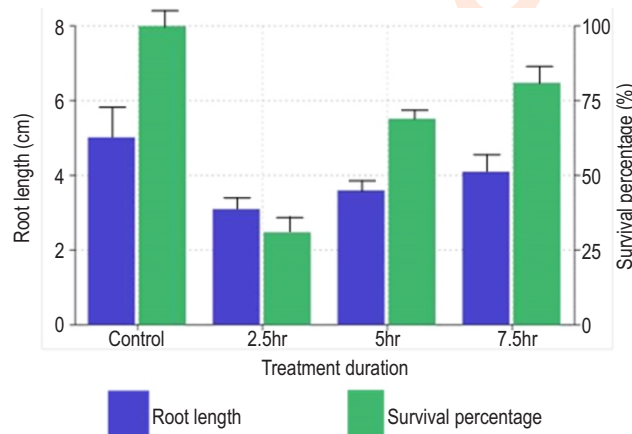


Fig. 6: Root length and seedling survival percentage.

thermotolerance potential. Traits like SCMR, leaf temperature regulation, and seed weight emerged as key indicators of stress tolerance and productivity, making them valuable selection targets for breeding heat-resilient cowpea varieties (Barros *et al.*, 2021; Kapazoglou *et al.*, 2023). To understand the interrelationship among the key morphological and physiological traits under high-temperature stress, Principal Component Analysis (PCA) and a heatmap were employed, focusing on the Raichur experiment. Principal Component Analysis was exclusively applied for Raichur plants to explore the physiological response towards thermotolerance in cowpea genotypes.

The correlation analysis revealed several statistically significant relationships among the studied traits. Notably, a strong positive correlation was observed between seed weight and pod yield ($r=0.96$), and between shoot dry weight and total dry matter ($r=0.94$), underscoring the role of biomass accumulation and seed development in determining yield (Dewangan *et al.*, 2022). Similarly, the number of pods per plant also showed a positive correlation with pod yield ($r=0.58$), indicating that pod-

bearing capacity is a key yield component under heat stress (Rani *et al.*, 2024). Plant height displayed moderate positive correlations with number of seeds per pod ($r=0.4$) and pod length ($r=0.31$), suggesting a partial link between vegetative vigor and reproductive output. Interestingly, the correlation between plant height and number of branches ($r = 0.39$), though positive, was relatively weak, indicating these traits can be selected independently. This flexibility allows breeders to optimize canopy architecture without necessarily compromising height-related traits (Deshpande *et al.*, 2018). In contrast, leaf temperature exhibited weak negative correlations with most traits, particularly plant height ($r=-0.25$). This pattern highlights the detrimental effect of high canopy temperatures on growth and development (Tambitkar *et al.*, 2020). Additionally, SPAD chlorophyll meter readings (SCMR) showed weak to moderate positive correlations with other traits, suggesting its potential as an indirect selection tool for photosynthetic efficiency under heat stress (Akbar *et al.*, 2017; Mohammed *et al.*, 2024).

The number of branches, apart from its moderate correlation with pod number, showed weak associations with

other traits. This indicates that branching behavior can be independently selected to tailor plant architecture to specific environmental conditions or agronomic needs (Manggoel *et al.*, 2012; Singh *et al.*, 2021). From a broader physiological perspective, the reduction in pod number and biomass under Raichur's heat stress conditions may reflect a shift in resource allocation (Allen *et al.*, 2018; Mathew *et al.*, 2023). Possible mechanisms include reduced photosynthate translocation, altered carbon partitioning, or increased metabolic costs associated with stress adaptation (Jarvis *et al.*, 2011; Rani *et al.*, 2024). These physiological trade-offs are critical considerations for developing heat-resilient cultivars. PCA effectively reduced the complexity of trait data set, revealing that traits such as plant height, shoot dry weight, and total biomass were main contributors to genotypic variability under heat stress. This supports the use of PCA as a tool for identifying priority traits under stress environments (Mathew *et al.*, 2023). Complementing PCA, the heat map analysis visually emphasized trait clusters. It confirmed strong positive linkages (seed weight and pod yield) and weak negative relationships (between leaf temperature and most growth-related traits). These visualizations provide a comprehensive understanding of trait interactions and help prioritize traits in breeding pipelines.

In conclusion, the combination of PCA, correlation analysis and heat map visualization provided clear, interpretable insights into trait dynamics under heat stress (Mohammed *et al.*, 2024). These findings emphasize the importance of integrated, trait-specific selection strategies to enhance cowpea productivity and resilience in the face of rising temperatures. The 20 germplasm lines with highest and lowest difference in dry matter accumulation (Fig. 4) were identified had contrasts for temperature induction response studies. For the tolerant germplasm, the TDM differences were relatively moderate, with IC-402172 showing the lowest difference at 0.68 and EC-458490 showing the highest at 9.7. In contrast, the susceptible germplasm showed much higher TDM differences, with values ranging from 49.55 (NBC-47) to 74.15 (EC-458483). These higher differences indicate that these genotypes accumulate significantly more dry matter under heat stress (Kumar *et al.*, 2016; Mathew *et al.*, 2023), suggesting them to be less tolerant under stress conditions and their biomass accumulation more affected by heat (Hussainbi *et al.*, 2023). The large difference in TDM between the tolerant and susceptible groups highlights the potential of tolerant genotypes to maintain growth and biomass accumulation under heat stress, making them promising candidates for breeding heat-resistant cowpea varieties. The survival of cowpea seedlings was high (95-100%) at temperatures up to 50°C, but sharply declined at 51°C and 52°C, dropping to 0% after 3 hr at 52°C. Longer exposure generally reduces survival, with a significant interaction between temperatures and time (Dewangan *et al.*, 2022), as indicated by a critical difference (CD) value of 4.1 (Fig. 5). The cowpea seedlings tolerated the heat well up to 50°C, with 51°C as a critical threshold for damage. Improved survival at longer exposure times may indicate a heat acclimation response, possibly involving heat shock proteins (Janni *et al.*, 2020).

Heat stress reduces root length, with the most severe decrease (38%) after 2.5 hr, while longer exposures (5 hr and 7.5 hr) showed lesser reduction. Seedling survival also decreased significantly, with the greatest drop (69%) at 2.5 hr, but only a 19% reduction after 7.5 hr (Fig. 5). Understanding cowpea's heat tolerance is vital for breeding programs aimed at developing heat-tolerant varieties for temperatures around 50-51°C (Fig.6) (Raviteja *et al.*, 2023). Further research is needed on the physiological and molecular mechanisms of this acclimation response and the applicability of these findings to field conditions, where temperature fluctuations and other factors exist.

Cowpea responses to heat stress varied by location, with Bangalore showing more favorable growth (higher chlorophyll, yield). Genotypes IC-249141 and EC-472267 excelled in Bangalore. Notably, IC-402172 in Raichur maintained yield despite higher temperatures, suggesting heat avoidance. Its consistent plant height and seed weight further highlight its potential. This research identifies key genetic resources and tolerant genotypes valuable for breeding heat-resilient cowpea varieties to enhance productivity under rising global temperatures.

Acknowledgment

We sincerely thank Basavaraj Byalihal for his assistance during experiments in Raichur, Karnataka, India.

Authors' contribution: **K. Prakash:** Investigation, data curation, methodology, supervision, revision and editing; **H.G. Praveen:** Data analysis, scientific justification of results, writing original draft; **K.S. Shashidhara:** Data analysis, manuscript revision and editing; **H. Manjunatha:** Involved in periodic assessment of field results; **M.S.P. Kanavi** and **S.T. Bhairappanavar:** Collaboratively conceptualized the technical outline of the research methodology, manuscript revision and editing; **K.M. Adarsh:** Primary investigation, data analysis; **R. Abhishree:** Extended idea and technical support for drafting the manuscript.

Funding: The work did not receive any fund.

Research content: The research content of manuscript is original and has not been published elsewhere.

Ethical approval: Not applicable.

Conflict of interest: The authors declare that there is no conflict of interest.

Data availability: The data underlying this article will be available upon request with the Corresponding author.

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology*.

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