

Identification of Thermo Tolerant Cowpea Genotypes by Field Evaluation

Abstract

Cowpea is mainly grown in the arid and semiarid regions at the global level. Studies have shown that temperature above 35°C affects the physiological processes and decreases the grain yield of cowpea. Hence, identification of thermo tolerant genotypes is necessary. In this regard, one hundred ninety-one genotypes were screened for yield attributes under field conditions at Raichur, Karnataka. The crop was exposed to a high temperature up to 41°C during the entire crop growth period. The plants experienced high levels of heat stress which led to an increase in mean leaf temperature, decreased mean SPAD chlorophyll meter reading (SCMR), total dry matter (TDM) and other yield attributing traits. Tolerant cowpea genotypes which showed minimum reduction in total dry matter compared to susceptible genotypes were identified. The tolerant genotypes IC-402172, EC-458453, EC-458470, NBC-21, NBC-14, EC-394708, CB-10, IC-458430, IC-249588 and EC-458490 can sustain the temperature up to 35°C without compromising the total dry matter. This can be used for further crop improvement programme to develop the tolerance in cowpea.

Comment [p1]: Establish the importance of cowpea

Comment [p2]: Field evaluation should also include yield data which is missing here.

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.], a C₃ species, is an important warm-season legume grown primarily in the semi-arid tropics (Timko and Singh, 2008). It is native to Africa but is widely cultivated and consumed in tropical and subtropical areas of Africa, Latin America, and Southeast Asia, as well as in the Southern United States (Appiah *et al.*, 2011). In India, the production of pulses is around 19.3 million tonnes, with a very low average productivity of 764 kg/ha (Yadav *et al.*, 2017). This low productivity highlights the urgent need for improved cultivation practices and the development of more resilient cowpea varieties.

Comment [p3]: Give latest yield/data

Cowpea is generally well-adapted to these environments, although high day (> 35°C) and night (> 20°C) temperatures reduce the number of pods and seed yield in many genotypes (Ismail and Hall, 1998). Understanding the specific thresholds of heat tolerance in different cowpea genotypes can help in breeding efforts aimed at enhancing resilience against climate variability.

Heat Stress (HS) is the most prominent abiotic concern for all crop plants (Bita and Gerats, 2013). HS negatively affects plant biomass accumulation, leading to a reduction in yield, especially in tropical and subtropical regions. A rise of 3-4 °C in temperature has been predicted to cause a reduction of 15-35 percent in crop productivity (Ortiz *et al.*, 2008). Increased night temperatures crucially affect cowpea yield, exacerbating the stress already imposed by daytime heat. Therefore, finding genotypes that can adapt to rising temperatures is essential to meet the world's expanding demand for food. Crop phenology and output are negatively impacted by high temperatures, resulting in lower overall yield and compromised quality.

Comment [p4]: There is no info available about the selection criteria

The identification and characterization of donor/parental lines for high-temperature tolerance would be a prerequisite for creating acceptable cultivars. Targeted breeding programs focusing on heat resilience can play a vital role in developing cowpea varieties that maintain productivity under stress. Therefore, the present study plans to use genetic variation to identify cowpea accessions that are tolerant to high temperatures, contributing to sustainable agriculture and food security in a warming world.

Materials and Methods

Experimental conditions

The present study was conducted at Turvihah, Sindhanur, Raichur district of Karnataka state. The field is located at 15°45' North latitude and 76°35' East longitude at an altitude of 1335 meter above the mean sea level. Soil textural class is deep black clayey with a soil of 6.4 (1:2.5, soil:water). During the experimental period at Raichur the T_{max} was 41 °C and T_{min} 23.4 °C with an average rainfall of 1.1 mm (Fig. 1).

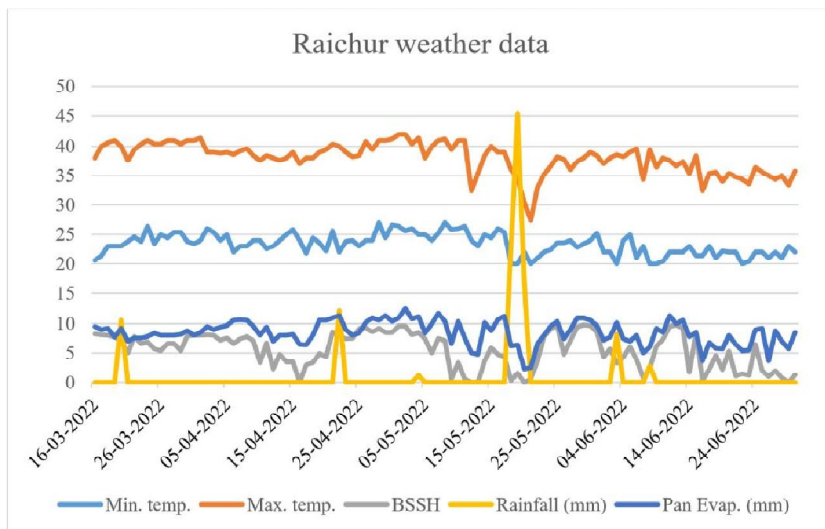


Fig. 1: Weather parameters recorded at Raichur from March to June

Experimental material

One hundred and ninety-one genotypes (191) of Cowpea were used in this field study. These seeds were obtained from All India Co-ordinated Pulses Improvement Project, G.K.V.K., Bangalore, Karnataka. Experiment was carried out in simple augmented design with one genotype in each line (Fig. 2). Ten seeds of each genotype were sown at a distance of 45 cm apart. Spacing given was 60 cm between the rows and 45 cm between plants.

Comment [p5]: Experimental design is missing

Physio-morphological and yield traits

All the parameters were measured in three plants from each genotype during the harvest stage except for physio-morphological traits like leaf temperature and SCMR which were taken during reproductive stage.

As a measure of relative greenness of leaves, a quick estimate of chlorophyll content, SCMR values were measured using SPAD502 Chlorophyll meter, Minolta, Japan.

Measurement of leaf temperature (LT) was made using infrared thermometer gun (Raytek, MINITEMP) held at 15 cm distance from the measuring top third leaf. Plant height was measured

on the main tiller of 3 randomly selected plants from base of the tiller to the tip of ear head. Number of branches was counted in 3 randomly selected plants from base of the stem to the tip of stem. Number of pods were counted by counting the total number of Pods in 3 randomly selected plants and expressed in numbers. Pod length is measured by measuring the length of pod using the scale. Number of seeds pod⁻¹ were measured by counting the total number of seeds in each pod. After taking the total pod weight, it was threshed, cleaned and seed weight was recorded. Seeds obtained from pods were dried in a constant weight using hot air oven and added to total pod weight to arrive at total dry matter (TDM).

Comment [p6]: Author should establish the selection criteria. Yield data is missing. How can you identify heat tolerant genotypes under field conditions without yield.

Statistical analysis

Analysis was made using XLSTAT package using Augmented. The analysis of variance and interpretation of data was done as per procedure given by Gomez and Gomez (1984). The level of significance used in 'F' and student's 'T' test was P=0.05. Critical difference values were recalculated whenever 'F' test was significant.

Phenotypic and Genotypic coefficient of variation

The co-efficient of variability both at phenotypic and genotypic level for root traits and other traits were computed by applying the formula as suggested by (Burton and Devane, 1953).

$$PCV\% = (P/X) \times 100$$

$$GCV\% = (G/X) \times 100$$

Where, P = Phenotypic standard deviation; G = Genotypic standard deviation; X = Grand mean of the character; PCV = Phenotypic coefficient of variation; GCV = Genotypic coefficient of variation

GCV and PCV were classified as suggested by Robinson *et al.*, 1949

$$\text{Low} = 0 - 10\%$$

$$\text{Moderate} = 10 - 20\%$$

$$\text{High} = > 20\%$$

Heritability

Broad sense heritability was estimated using the following formula (Hanson *et al.*, 1956).

$$H = (V(g) / V(p)) \times 100$$

Where, H = broad sense heritability; V (g) = Genotypic variance; V (p) = Phenotypic variance; Heritability was categorized into following three classes.

Low heritability = 0-30%

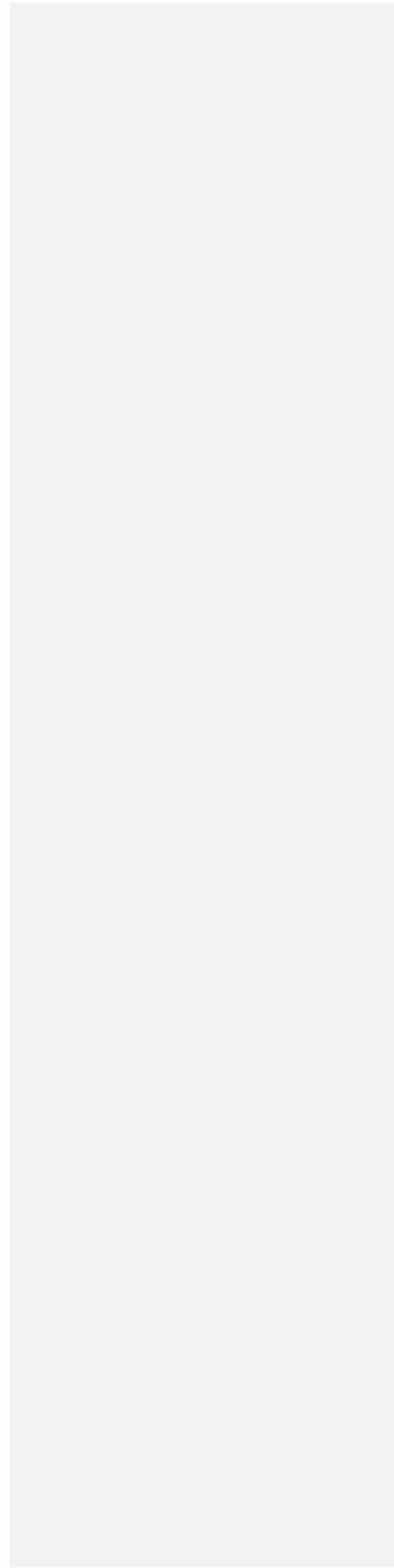
Medium heritability = 30-60%

High heritability = 60% and above

EC-458469	NBC-44	202804(83)	NBC-24	GC-3	NBC-47	TOME-774	IC-198326-38
IC-462099	EC-472250	EC-170584(B-9)	IC-402166	IC-202290	EC-458442	EC-458470	NBC-40
IC-402174	IC-4506	NBC-16	IC-402172	EC-394839	IC-202711(58)	CB-10	IC-402162
NBC-8	EC-458438	NBC-39	IC-402101	EC-458489	201095(52)	IC-1071	EC-458438
IC-402154	IC-402125	NBC-21	IC-206240	EC-458483	KM-5	EC-458425	NBC-7
97767(10)	EC-394779	C-33	C-157	IC-402106	IC-1071	IC-402048	NBC-98
IC-402164	IC-402162	IC-402175	NBC-7	IC-249141	EC-458418	27749(25)	IC-402161
IC-402180	EC-170584-1.1	EC-394708	V-578	EC-394708	NBC-6	EC-394838	IC-202781
202804(83)	IC-249593	IC-330996	GENOTYPE-36	IC-402159	NBC-25	IC-202825	NBC-12
EC-458440	IC-402098	IC-402172	IC-402159	IC-202792(78)	NBC-36	EC-458511	NBC-40
	↔	↔	↔	↔	↔	↔	↔
C-325	IC-249588	IC-249593	EC-170584 B-9	NBC-51	C-33	IC-10171	NBC-14
NBC-21	IC-402114	IC-202781	V-578(C)	NBC-43	202827993)	NBC-27	IC-402159
IC-402182	IC-202777	IC-1071	IC-202777	IC-58905	NBC-33	EC-390287	EC-458417
EC-394778	EC-472271	202854(97)	IC-402161	EC-458489	EC-402159	CPD-15	V-604-7-293
IC-2010	EC-394839	IC-4506	EC-458402	EC-472267	C-325	EC-472250	NBC-19
	BUND 0.6 metre	BUND 0.6 metre	BUND 0.6 metre	BUND 0.6 metre	BUND 0.6 metre	BUND 0.6 metre	BUND 0.6 metre
EC-458453	EC-402104	IC-2591054	EC-170604	IC-49586	C-720	EC-458490	
V-578	KBC-2	V-585	NBC-30	V-485(C)	198355(45)	EC-458418	
EC-458480	CP-98	198355(45)	VC-458492	NB-18	11-9/15499-38	IC-402090	
NBC-41	IC-402090	IC-202781	IC-253251	EC-458411	NBC-42	EC-394779	
C-152	IC-458430	V-240	EC-1705746	IC-402175	NBC-29	V-16	
IC-402104	IC-249593	IC-402166	IC-2591054	202827(92)	EC-458480	202825-89	
IC-1061	IC-402101	EC-458480	EC-472257	IC-249141	NBC-32	IC-19832936	
IC-25105	CB-10	EC-458485	IC-402180	IC-257428	V-585	NBC-23	
EC-458473	IC-202781	NBC-38	GENOTYPE	EC-472252	ETC-27	NBC-42	
EC-458402	EC-170584	C-24-1	11-9/ K-499-38	IC-402164	IC-20286(99)	EC-458473	

Fig.2:LayoutofExperimentalunit

UNDER PEER REVIEW



Results and Discussion

Variability for various physio-morphological and yield traits among cowpea genotypes

Randomly selected 191 germplasm were evaluated under field conditions during summer season, 2022 at Raichur location. Various Physio-morphological and yield attributing traits were measured. Significantly continuous variability was observed among all the physio-morphological and yield traits (Fig.3). Significant variability was observed for various physio-morphological traits like Plant height (cm), Number of Branches, SCMR Leaf Temperature (°C). Further, significant variability was observed for various yield traits like Seed weight (g/plant), Pod length (cm), Number of seeds per pod, Number of pods per plant, Shoot dry weight (g/plant), Pod yield (g/plant) and TDM (g/plant). A positively skewed distribution towards the lower values was observed (Fig.3).

Physio-morphological traits

Plant height (cm)

Plant height varied 25.28 cm (EC-394839) to 67.24 cm (NBC-27) with the mean of 44.33 cm (Table 1). The heritability was 89.30%, with GCV and PCV values of 17.11% and 18.11 % respectively (Table 2). Plant height revealed genetic advance of 14.77 % (Table 1 and Table 2). The significant variability in plant height suggests potential for selective breeding. The high heritability indicates that plant height is a trait that can be effectively improved through breeding programs.

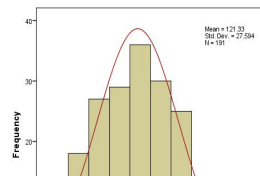
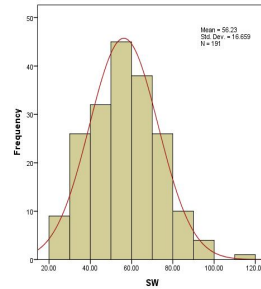
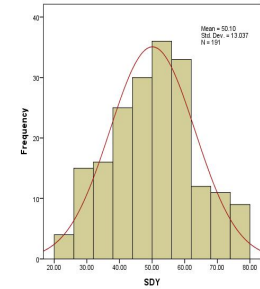
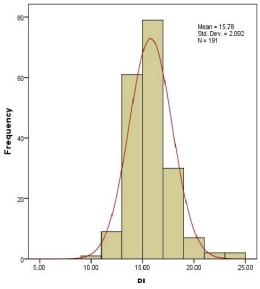
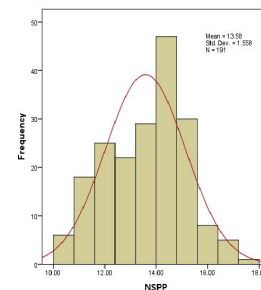
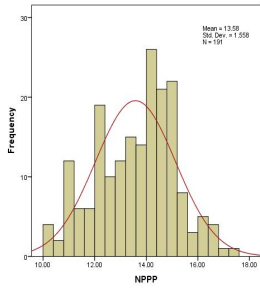
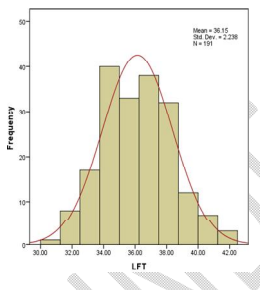
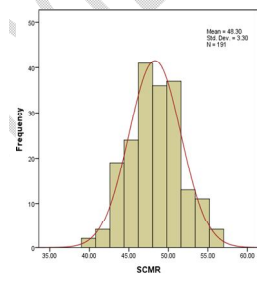
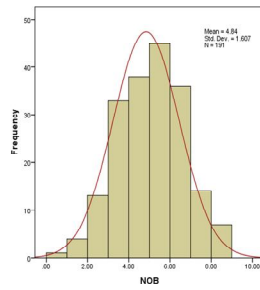
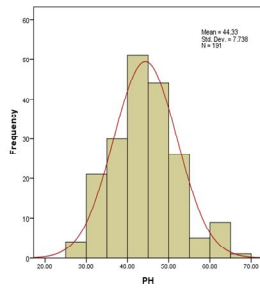


Fig.3: Continuous variability observed for various traits among cowpea germplasm lines. PH: Plant height (cm), NOB: Number of Branches, SCMR, LFT: Leaf Temperature (°C), NPPP: Number of pods per plant, NSPP: Number of seeds per pod, PL: Pod length (cm), SDY: Shoot dry weight(g/plant), SW: Seed weight(g/plant), TDM: Total dry matter(g/plant).

Comment [p7]: Error bars are missing

Number of branches

Number of branches showed a very high heritability of 95.20%, with GCV and PCV values of 33.10 and 33.93 % respectively (Table 2). Number of branches revealed genetic advance of 3.22% (Table 2). Increase in temperature increases the number of nodes and leaves, but it reduces the length of internodes and plant height (Allen *et al.*, 2018). The increase in temperature affected the plant growth and development which finally led to decreased plant height. The increase in temperature beyond optimum has led to the decrease in number of branches.

SCMR

SCMR varied from a minimum of 39.11 (NBC-47) to 55.92 (NBC-47) with a mean of 48.30 at Raichur (Table 1). SCMR showed heritability was 49.80 %, with GCV and PCV values of 5.91 % and 8.38% respectively. SCMR gives the chlorophyll content in leaves. Increase in the temperature beyond optimum results in degradation of chlorophyll (Bita and Gerats, 2013). The increase in temperature beyond optimum (35°C) has led to the degradation of chlorophyll content in leaves at Raichur.

Leaf temperature (°C)

Many crops have demonstrated that transpiration cooling is a crucial mechanism for heat avoidance, and leaf cooling characteristics have been exploited in breeding for both drought

and heat tolerance (Deva *et al.*, 2020). Leaf temperature ranged from 30.33°C (IC-402172) to 42.33°C (V-578) with a mean of 36.16°C (Table 1). Leaf temperatures showed a medium heritability of 42.30 %, with GCV and PCV values of 5.13 and 7.89 % respectively. It is reported that transpiration cooling is the important mechanism for heat tolerance (Deva *et al.*, 2020). The substantial range in leaf temperature indicates variability in heat tolerance among genotypes, suggesting opportunities for breeding plants that can better manage heat stress through improved transpiration cooling mechanisms.

Number of pods per plant

Number of pods per plant varied from a minimum of 16.67 (C-152) to 62.33 (IC202867) with a mean of 37.62 (Table 1). Number of pods per plant showed heritability of 94.80 %, with GCV and PCV values of 26.90% and 27.63% respectively (Table 2). The high heritability and genetic variability in pod number signify that selective breeding could yield genotypes with increased pod production, crucial for enhancing overall yield.

Pod length (cm)

Pod length varied significantly from 9.82 cm (EC-170584B-9) to 23.85 cm (C-157) with a mean of 15.78 cm. Pod length revealed genetic advance of 20.31% (Table 2). The significant genetic advance in pod length indicates a promising avenue for improvement. Understanding environmental factors that influence pod development will be essential for breeding efforts.

Number of seeds per pod

Number of seeds per pod varied from 10.00 (IC-458430) to 17.21 (27749(25)) with a mean of 13.58. The heritability was 74.50 %, with GCV and PCV values of 10.96% and 12.70% respectively (Table 2). While the heritability is moderate, it is essential to address the impact of heat stress on seed set to improve yield; breeding efforts should focus on enhancing this trait in heat-prone environments.

Shoot dry weight (g/plant)

Shoot dry weight varied from 21.83 gm (IC-330996) to 79.47 gm (V-485{C}) with a mean of 50.10 gm (Table 1). Shoot dry weight showed heritability of 94.60%, with GCV and PCV values of 25.78% and 26.50% respectively (Table 2). The high heritability in shoot dry weight suggests a strong genetic basis, allowing breeders to select for genotypes that can maintain biomass under stress, thereby potentially improving overall yield.

Seed weight(g/plant)

Seed weight ranged from 25.02 gm (NBC-41) to 116.90 gm (EC-472267) with a mean of 56.23 gm (Table 1). Seed weight showed a very high heritability of 95.60%, with GCV and PCV values of 29.40% and 30.07% respectively (Table 2).

Heat stress has a huge impact on yield attributes of cowpea. Higher temperature during critical stages like flowering and pod filling leads to embryo abortion (Warrag and Hall *et al.*, 1984). In the present study, the decrease in pod yield and seed weight could be due to ovule and ovary abnormality (Devasirvatham *et al.*, 2013). Due to higher temperature in Raichur led to decreased mean pod length. Also, it affects the number of pods, finally affecting the seed yield and pod yield.

Total dry matter(g/plant)

Total dry matter varied significantly from 65.03 gm (IC-330996) to 183.29 gm (IT-97 K-499-38) with a mean of 121.33 gm. Total dry matter showed a heritability of 93.10 %, with GCV and PCV values of 22.47% and 23.29% respectively. Total dry matter revealed a genetic advance of 54.17% (Table 1 and Table 2). The significant genetic advancement in total dry matter demonstrates that selection for this trait can yield benefits in biomass accumulation, essential for enhancing overall plant productivity under varying environmental conditions.

Table 1: Variability in physio-morphological and yield traits among cowpea genotypes

Traits	Mean	Min	Max	SD	CV(%)	Std.Error	Skewness	Kurtosis
PH(cm)	44.33	25.28	67.24	7.72	5.934	1.52	0.33	0.11
NOB	4.84	0.00	8.65	1.60	6.213	0.17	-0.13	-0.22
SCMR	48.30	39.11	55.92	3.29	5.932	1.65	0.04	-0.39
LT(°C)	36.15	30.33	42.33	2.23	5.974	1.25	0.10	-0.29
NPPP	37.62	16.67	62.33	10.19	6.202	1.35	0.05	-0.82
PL(cm)	15.78	9.82	23.85	2.09	5.951	0.54	0.70	1.94
NSPP	13.58	10.00	17.21	1.55	5.936	0.47	-0.19	-0.47
SDY(g)	50.10	21.83	79.47	13.00	6.166	1.78	0.07	-0.44
SW(g)	56.23	25.02	116.90	16.61	6.272	2.04	0.45	0.13
TDM(g)	121.33	65.03	183.29	27.52	6.133	4.30	0.00	-0.66

nsP >0.05; * P ≤0.05; ** P ≤0.01

Table 2: Genetic variability in relevant physio-morphological and yield traits among cowpea genotypes

Traits	Mean	GCV	PCV	ECV	h ² (BroadSense)	GA
PH(cm)	44.33	17.11	18.11	5.93	89.30	14.77
NOB	4.84	33.10	33.93	7.45	95.20	3.22
SCMR	48.30	5.91	8.38	5.94	49.80	4.15
LT(°C)	36.15	5.13	7.89	5.99	42.30	2.49
NPPP	37.62	26.90	27.63	6.15	94.80	32.78
PL(cm)	15.78	12.80	14.11	6.30	82.30	20.31
NSPP	13.58	10.96	12.70	5.94	74.50	3.77
SDY(g)	50.10	25.78	26.50	6.41	94.60	2.65
SW(g)	56.23	29.40	30.07	6.27	95.60	33.31
TDM(g)	121.33	22.47	23.29	6.13	93.10	54.17

It was interesting to note that the heritability in the broad sense for shoot dry weight, pod yield and TDM was significantly higher. The increase in temperature may have resulted in reduced growth rates and this can be visualized from the lower average for all the physio-morphological and yield traits among the accessions (Fig. 1). The increase in temperature has led to decrease in length of internodes finally affecting the plant height and number of branches (Allen *et al.*, 2018). Heat stress also led to ovule abnormality which finally led to reduced seed set and pod yield (Devasirvatham *et al.*, 2013). The decreased pod yield and dry matter led to reduced mean TDM.

Relationship among physio-morphological and yield traits

In the current study, TDM was used as a dependent variable and its related traits as independent variables. All the traits showed positive effect on TDM, while the shoot dry weight showed the highest and direct positive effect on TDM which reveals the stem portion is the major contributor to the total biomass. Similarly, seed weight and number of pods per plant showed higher and positive direct effect on TDM. Negligible residual values were observed (Table 3), which indicates that all the traits have strong genetic determination on TDM.

To determine the most desirable trait for further selection of germplasm, the correlation studies between the physio-morphological traits such as Leaf temperature and TDM, SCMR and TDM in both the locations showed non-significant relationship. Screening of cowpea germplasm lines based on SCMR and leaf temperature would be the best criteria for identifying tolerant and susceptible germplasm for high temperature tolerance (McDonald *et al.*, 1997). And also, TDM was also considered as a suitable trait for screening tolerant germplasm lines. Tolerant cowpea genotypes which showed minimum reduction in total dry matter compared to susceptible genotypes were identified. The tolerant genotypes IC-402172, EC-458453, EC-458470, NBC-21, NBC-14, EC-394708, CB-10, IC-458430, IC-249588 and EC-458490 can sustain the temperature up to 35°C without compromising the total dry matter.

Discussion

Conclusion

Comment [p8]: Discussion section is missing completely

This study highlights the significant potential of cowpea (*Vigna unguiculata*) as a resilient crop capable of adapting to the challenges posed by heat stress in semi-arid regions. Through the evaluation of a diverse panel of 191 germplasm accessions, critical insights into the genetic variability and heritability of yield attributes under high temperature conditions were obtained. The identification of tolerant genotypes, supported by robust field assessments, underscores the importance of targeted breeding efforts to enhance heat tolerance. The genotypes demonstrating resilience, such as IC-402172 and EC-458453, offer valuable resources for future crop improvement programs aimed at ensuring food security in the face of climate change. Overall, this research not only contributes to our understanding of cowpea's adaptive traits but also emphasizes the necessity of developing heat-resistant varieties to sustain agricultural productivity in vulnerable regions.

Comment [p9]: Mention how these genotypes demonstrate resilience?

UNDER PEER REVIEW

Table3:Pearsoncorrelationcoefficientmatrixofphysio-morphologicalandyieldtraitsatRaichur

PC	PH (cm)	NOB	SCMR	LT (°C)	SW(g)	PL (cm)	NSPP	NPPP	SDW(g)	TDM	PY(g)
PH(cm)	1										
NOB	0.332**	1									
SCMR	0.111*	0.128*	1								
LT(°C)	0.0422	-0.106*	0.331**	1							
SW(g)	0.0693	0.188**	0.219**	0.103*	1						
PL(cm)	0.0777	0.0204	0.210**	0.184**	0.0805	1					
NSPP	0.172**	0.0486	0.170**	0.183**	0.162**	0.371**	1				
NPPP	0.121*	0.322**	0.095*	0.110*	0.537**	-0.085*	0.0503	1			
SDW(g)	-0.0092	0.113*	0.129*	0.193**	0.731**	0.037	0.123*	0.533**	1		
TDM(g)	0.0438	0.168**	0.206**	0.168**	0.946**	0.0743	0.165**	0.577**	0.912**	1	
PY(g)	0.0799	0.190**	0.242**	0.128*	0.9991**	0.094*	0.177**	0.541**	0.733**	0.948**	1

References

- ALLEN JR, L.H., ZHANG, L., BOOTE, K.J. AND HAUSER, B.A., 2018, Elevated temperature intensity, timing, and duration of exposure affect soybean internode elongation, main stem node number, and pod number per plant. *The Crop Journal*, **6**(2), pp.148-161.
- APPIAH, F., ASIBUO, J.Y. AND KUMAH, P., 2011, Physicochemical and functional properties of bean flours of three cowpea (*Vigna unguiculata* L. Walp) varieties in Ghana.
- BITA, C.E. AND GERATS, T., 2013, Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. *Front. Plant Sci.*, **4**: 273.
- BURTON, G. W. AND DEVANE, D. E., 1953, Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material 1. *Agron. J.*, **45**(10):478-481.
- DEVA, C.R., URBAN, M.O., CHALLINOR, A.J., FALLOON, P. AND SVITÁKOVÁ, L., 2020, Enhanced leaf cooling is a pathway to heat tolerance in common bean. *Front. Plant Sci.*, **11**: 19-30.
- DEVASIRVATHAM, V., GAUR, P.M., MALLIKARJUNA, N., RAJU, T.N., TRETOWAN, R.M. AND TAN, D.K., 2013, Reproductive biology of chickpea in response to heat stress in the field is associated with the performance in controlled environments. *Field Crops Res.*, **142**:9-19.
- HANSON, C., ROBINSON, H., and COMSTOCK, R., 1956, Biometrical studies of yield in segregating populations of *Korean lespedeza* L. *Agron. J.*, **48**(6):268-272.
- ISMAIL, A.M. AND HALL, A.E., 1998, Positive and potential negative effects of heat tolerance genes in cowpea. *Crop Sci.*, **38**(2), 381-390.
- MCDONALD, G.K. AND PAULSEN, G.M., 1997, High temperature effects on photosynthesis and water relations of grain legumes. *Plant and soil*, **196**(1): 47-58.
- ORTIZ, R., SAYRE, K.D., GOVAERTS, B., GUPTA, R., SUBBARAO, G.V., BAN, T., HODSON, D., DIXON, J.M., ORTIZ-MONASTERIO, J.I. AND REYNOLDS, M., 2008, Climate change: can wheat beat the heat? *Agric. Ecosyst. Environ.*, **126**(1-2):465-8
- TIMKO, M.P. AND SINGH, B.B., 2008, Cowpea, a multifunctional legume. In *Genomics of tropical crop plants*: **227-258** Springer, New York, NY.

- WARRAG, M.O.A. AND HALL, A.E., 1984, Reproductive responses of cowpea (*Vigna unguiculata* (L.) Walp.) to heat stress. I. Responses to soil and day air temperatures. *Field Crops Res.*, **8**, 3-16.
- YADAV, T., NISHA, K.C., CHOPRA, N.K., YADAV, M.R., KUMAR, R., RATHORE, D.K., SONI, P.G., MANARANA, G., TAMTA, A., KUSHWAH, M. AND RAM, H., 2017, Weed management in cowpea - A review. *Int. j. curr. microbiol. appl. sci.*, **6**(2):1373-1385.

UNDER PEER REVIEW