Original Research Article

Evaluation of Thermo Tolerant Cowpea Genotypes by Field Conditions

Abstract

Cowpea is mainly grown in the arid and semiarid regions at the global level. The temperature above 35°C affects the morpho-physiological processes and decreases the biomass.Hence,identificationofthermotolerantgenotypesisnecessaryto ensure food security in the face of climate change, allowing farmers to cultivate resilient varieties.Inthisregard,onehundred ninety-one genotypes were screened for yield attributes under field conditions at Raichur, Karnataka.Thecropwasexposedtoahighertemperatureup to 41°C during the entire crop growth period. The plantsexperiencedhigh levels of heat stress which led toincreaseinmeanleaftemperature,decreasedmeanSPADchlorophyllmeterreading(SCMR),totaldry matter (TDM) and other yield attributing traits.Tolerant cowpea genotypes which showedminimum reduction in total dry matter compared to susceptible genotypes where identified. The tolerant genotypesIC-402172, EC-458453, EC-458470,NBC-21,NBC-14,EC-394708,CB-10,IC-458430,IC-249588andEC-458490can sustain thetemperatureup to 35°Cwithout compromising thetotal dry matter. This can be used for further cropimprovement programme to develop themotolerance.

Key word: Cowpea, seed yield, genetic variation, crop growth, legume

UNDER PEER REVIEW

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.], a C_3 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

(Olorunwa*et al*., 2023). This low productivity highlights the urgent need for improved cultivation practices and the development of more resilient cowpea varieties.

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 (Allen *et al*., 2018). 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 is the most prominent abiotic concern for all crop plants (Bita and Gerats, 2013). It 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(Allen *et al*., 2018).Tolerant genotypes in cowpea can be selected based on Total Biomass (TBM), include traits such as optimal plant height and structure, high leaf area index for enhanced photosynthesis(Olorunwa*et al*., 2023).

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

Experimentalconditions

The present study was conducted atTurvihal, Sindhanur, Raichur district of Karnataka state. The field is located at 15º45¹ Northlatitude and 76º35¹ East longitude at an altitude of 1335 meter above the mean sealevel.SoiltexturalclassisdeepblackclayeywithapHofsoil6.4(1:2.5,soil:water). During the experimental period at Raichur the maximum temperature was 41 °Candminimum temperature was23.4°Cwithanaveragerainfallof1.1 mm (Fig.1).

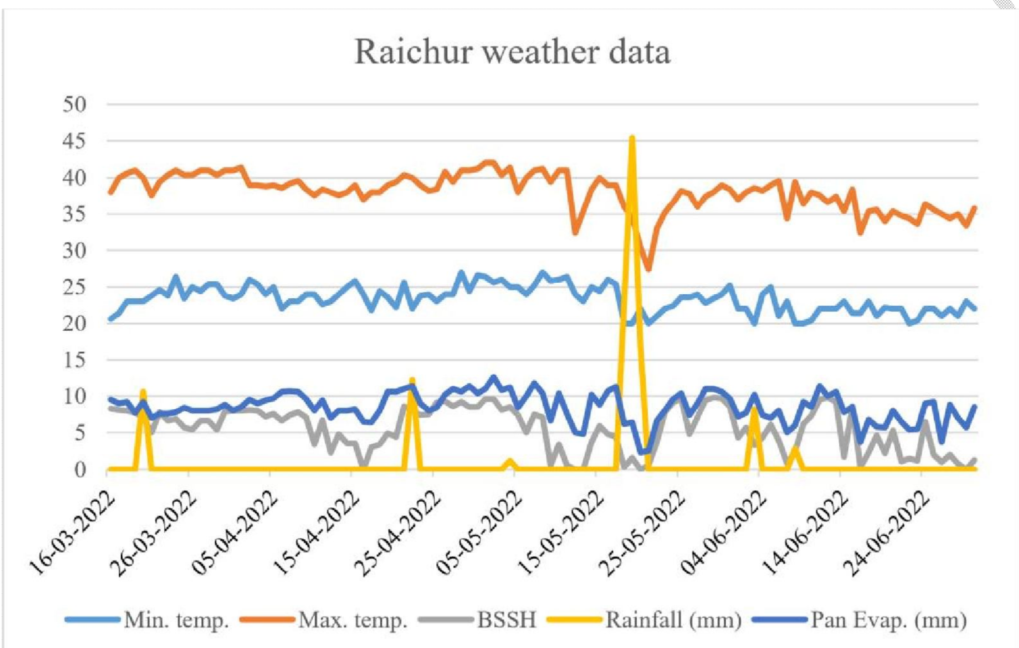


Fig. 1: Weather parameters recorded at Raichur from March to June, 2022

Experimentalmaterial

Onehundredandninety-onegenotypes(191)ofCowpeawereusedinthisfieldstudy.TheseedswereobtainedfromAllIndiaCo-ordinatedPulsesImprovementProject, G.K.V.K., Bangalore, Karnataka. Experiment was carried out in simple augmented design with onegenotypein each line(Fig.2). Tenseedsof eachgenotypeweresown atdistanceof45cmapart. Spacinggivenwas60cmbetweentherowsand45cmbetweenplants.

Physio-morphological and yield traits

All the parameters were measured in three plants from each genotype duringtheharveststageexceptforphysio-morphologicaltraitslikeleaftemperatureand SCMRwhich weretaken duringreproductivestage.

As a measure of relative greenness ofleaves,aquickestimateofchlorophyllcontent,SCMRvaluesweremeasuredusingSPAD502Chlorophyll meter,Minolta, Japan.

Measurement of leaf temperature (LT) was made using infraredthermometer gun (Raytek, MINITEMP) held at 15cm distance from the measuring topthirdleaf.Plant height was measured on the main tiller of 3 randomly selectedplantsfrom baseof thetiller to thetip of ear head. Number of branches was counted in 3 randomly selected plantsfrombaseof thestem to the tip of stem. Numberof podswerecountedbycountingthetotalnumber of Podsin3 randomlyselected plants and expressed in numbers. Pod lengthis measuredbymeasuringthelength ofpodusingthe scale. Numberofseedspod^{-1}weremeasuredbycountingthetotalnumberof seeds in eachpod. Aftertakingthetotalpodweight,itwasthreshed,cleanedandseedweightwasrecorded. Seedsobtainedfrompodsweredriedinaconstantweightusinghotairoven andadded to total pod weightto arriveattotal drymatter (TDM).

Statisticalanalysis

AnalysiswasmadeusingXLSTATpackageusing Augmented. Theanalysisofvarianceandinterpretationofdatawasdoneasperproceduregivenby GomezandGomez(1984).Thelevelofsignificanceusedin‘F’andstudent’s‘T’testswasP=0.05. Criticaldifferencevalueswerecalculatedwhenever‘F’testwassignificant.

PhenotypicandGenotypiccoefficientofvariation

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

UNDER PEER REVIEW

coefficient of variation

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

Low = 0 -10%

Moderate = 10- 20%

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

UNDER PEER REVIEW

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	BUND 0.6 metre	IC-249588	BUND 0.6 metre	IC-249593	BUND 0.6 metre	EC-170584 B-9	BUND 0.6 metre	NBC-51	BUND 0.6 metre	C-33	BUND 0.6 metre	IC-10171	BUND 0.6 metre	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-201©		EC-394839		IC-4506		EC-458402		EC-472267		C-325		EC-472250		NBC-19
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		IT-9715499-38		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		IT-97 K-499-38		IC-402164		IC-202867(99)		EC-458473		

UNDER PEER REVIEW

Fig.2:LayoutofExperimentalunit

Results and Discussion

Variabilityforvariousphysio-morphologicalandyieldtraitsamongcowpeagenotypes

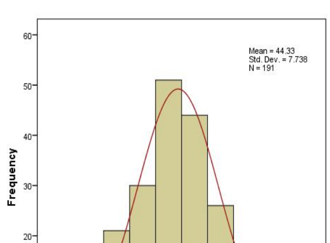
Randomly selected 191 germplasm were evaluated under field conditions during summerseason, 2022 at Raichur location. Various Physio-morphological and yieldattributing traits were measured. Significantly continuous variability was observed among all thephysio-morphologicalandyieldtraits(Fig.3). Significant variability was observed for various physio-morphological traits likePlant 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 skeweddistributiontowards thelower values was observed (Fig.3).

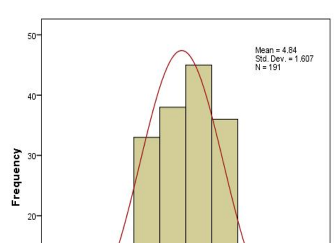
Physio-morphologicaltraits

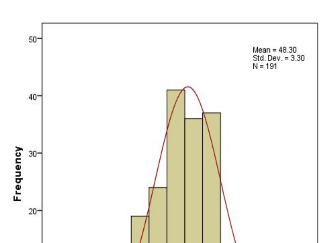
Plantheight (cm)

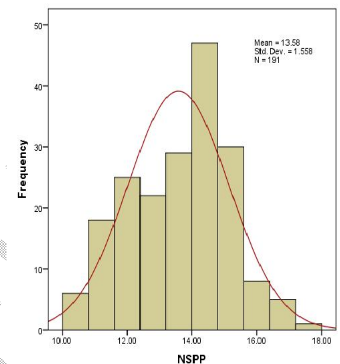
Plantheightvaried25.28 cm (EC-394839) to 67.24 cm (NBC-27) with themean of 44.33 cm (Table 1). Theheritabilitywas89.30%,withGCVandPCVvalues of17.11%and18.11 % respectively (Table 2). Plant height revealed genetic advance of 14.77 % (Table1andTable2).The significant variability in plant height suggests potential for selective breeding. The high heritability indicates that plant height is a trait that can be effectively improved through breeding programs.

UNDER PEER REVIEW









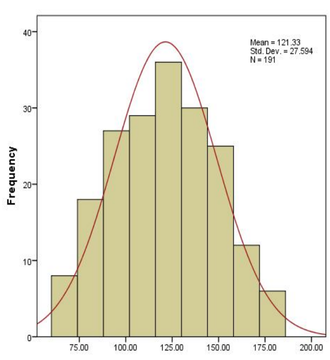


Fig.3: Continuousvariabilityobservedforvarioustraitsamongcowpeagermplasmlines. PH: Plant height (cm), NOB: Number of Branches, SCMR, LFT: Leaf Temperature (°C), NPPP: Number of pods per plant, NSPP: Number of seeds per pod, PL: Pod length (cm), SDY: Shoot dry weight(g/plant), SW: Seed weight(g/plant), TDM: Total dry matter(g/plant).

Numberofbranches

Numberofbranchesshowedaveryhighheritabilityof95.20%,withGCVandPCVvaluesof33.10and33.93 % respectively (Table 2). Number of branches revealed genetic advance of 3.22% (Table 2). Increaseintemperatureincreasesthenumberofnodesandleaves,butitreducesthe lengthofinternodesandplantheight(Allen*et al.*,2018).Theincreaseintemperatureaffectedtheplantgrowthanddevelopmentwhichfinallyledtodecreasedplantheight.Theincreaseintemperaturebeyondoptimum has ledto thedecreaseinnumber ofbranches.Increased temperatures can enhance the number of nodes and leaves but negatively impact internode length and overall plant height, leading to a decline in branch formation beyond optimal conditions.

SCMR

SCMRvariedfromaminimumof39.11 (NBC-47) to 55.92 (NBC-47) with a mean of 48.30atRaichur(Table1).SCMRshowedheritability was 49.80 %, with GCV and PCV values of 5.91 % and 8.38% respectively.SCMR gives the chlorophyll content in leaves. Increase in thetemperaturebeyondoptimumresultsindegradationofchlorophyll(Bita and Gerats, 2013).Theincreaseintemperaturebeyondoptimum(35°C)hasledtothedegradationofchlorophyllcontentofleavesatRaichur.

Leaftemperature(°C)

Many crops have demonstrated that transpiration cooling is a crucial mechanism for heatavoidance, and leaf cooling characteristics have been exploited in breeding for both drought andheat tolerance (Deva *et al., 2020*). Leaf temperature ranged from 30.33°C (IC-402172) to42.33°C(V-578)withameanof36.16°C(Table1).Leaftemperatureshowedamediumheritability of 42.30 %, with GCV and PCVvalues of 5.13 and 7.89 % respectively. Itisreportedthattranspirationcoolingistheimportantmechanismforheattolerance(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 (Yadav *et al.*, 2017).

Numberofpodsperplant

Numberofpods perplant variedfrom minimumof16.67 (C-152) to 62.33(IC202867) with a mean of 37.62 (Table 1). Number of pods per plant showed heritabilityof 94.80 %, with GCVandPCVvaluesof26.90%and27.63%respectively(Table2).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.The number of pods per plant demonstrated high heritability and genetic variability, underscoring the feasibility of breeding programs aimed at enhancing pod production. This trait is critical for increasing overall yield, especially in the face of environmental stressors that can limit reproductive success.

Podlength(cm)

Pod length varied significantly from9.82cm(EC-170584B-9)to23.85(C-157)withameanof15.78cm.Pod length revealed genetic advance of 20.31% indicating that this trait can be effectively improved through selective breeding(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.Understanding the environmental influences on pod development will be essential for optimizing yield outcomes in various conditions.

Numberof seedsperpod

Numberofseedsperpodvaried from10.00(IC-458430)to17.21(27749(25))withameanof13.58. 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.

Shootdryweight(g/plant)

Shoot dry weight varied from 21.83 cm (IC-330996) to 79.47 (V-485{C})with a mean of 50.10 gm (Table 1). Shoot dry weight showedheritabilityof94.60%,withGCVandPCVvaluesof 25.78%and26.50%respectively, suggesting a strong genetic foundation for this trait(Table2).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.

UNDER PEER REVIEW

Seedweight(g/plant)

Seedweightrangedfrom25.02gm.(NBC-41)to116.90gm.(EC-472267)withameanof 56.23 gm (Table 1). Seed weight showed a very high heritability of95.60%,withGCVandPCVvalues of29.40%and30.07% respectively (Table2).

Heat stress has a huge impact on yield attributes of cowpea. Higher temperature duringcritical 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 ovule andovary abnormality (Devasirvatham*et al.*, 2013). Due to higher temperature in Raichur led todecreased mean pod length. Also, it affects the number of pods,finallyaffectingtheseedyield and podyield.

Totaldrymatter(g/plant)

Totaldrymattervariedsignificantlyfrom65.03gm.(IC-330996)to183.29 gm. (IT-97 K-499-38) with a mean of 121.33 gm. Total dry mattershowedaheritabilityof93.10 %, with GCVand PCV values of 22.47% and 23.29% respectively. Total dry matter revealed geneticadvanceof54.17%(Table1andTable2). 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. 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).

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

UNDER PEER REVIEW

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

Table2:Geneticvariabiltyinrelevantphysio-morphologicalandyieldtraitsamongcowpeagenotypes. 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).

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, podyield and

UNDER PEER REVIEW

TDM was significantly higher. The increaseintemperature,mayhaveresultedinreducedgrowthratesandthiscanbevisualizedfromtheloweraverageforallthephysio-morphologicalandyieldtraitsamongtheaccessions(Fig. 1). The increase in temperature has led to decrease in length ofinternodesfinallyaffectingtheplantheightandnumberofbranches(Allen*et al.*,2018).Heatstressalso 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.

Relationshipamongphysio-morphologicalandyieldtraits

Inthecurrentstudy,total dry matter (TDM)wasusedasdependentvariableanditsrelatedtraitsasindependent variable. All the traits showed positive effect on TDM, while the shoot dry weightshowed the highest and direct positive effect on TDM which reveals the stem portion is the majorcontributortothetotalbiomass.Similarly,seedweightandnumberofpodsperplantshowedhigherandpositivedirecteffectonTDM.Negligibleresidualvalueswereobserved(Table3),whichindicatesthat allthetraitshavestronggeneticdeterminationon TDM.The strong genetic correlation among traits emphasizes the importance of integrated breeding approaches to enhance biomass and yield, while minimizing the impacts of environmental stressors.

To determine the most desirable trait for further selection of germplasm, the correlationstudies between the physio-morphological traits such as Leaf temperature and TDM, SCMR andTDM in both the locations showed non-significant relationship. Screening of cowpeagermplasm lines based on SCMR and leaf temperature would be the best criteria for identifyingtolerant and susceptible germplasm for high temperature tolerance (McDonald *et al.*,1997).And also, TDM was also considered as a suitable trait for screening tolerant germplasmlines. Tolerant cowpea genotypes which showedminimum reduction in total dry matter compared to susceptible genotypes where identified. The tolerant genotypesIC-402172, EC-458453, EC-458470,NBC-21,NBC-14,EC-394708,CB-10,IC-458430,IC-249588andEC-458490can sustain thetemperatureup to 35^{o}Cwithout compromising thetotal dry matter.These tolerant genotypes can be further validated by multi-location trails and selected for breeding programmes to check for both high-yield and thermo-tolerance.

UNDER PEER REVIEW

Conclusion

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.

UNDER PEER REVIEW

Table3:Pearsoncorrelationcoefficientmatrixofphysio-morphologicalandyieldtraitsatRaichur. 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), PY: Pod Yield (g).

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

PEER REVIEW

Disclaimer (Artificial intelligence)

Author(s) hereby declare that generative AI technologies ChatGPT var40 mini has been used and NO text-to-image generators have been used during writing or editing of this manuscript.

References

- Allen Jr LH, Zhang L, Boote KJ, Hauser BA. Elevated temperature intensity, timing, and duration of exposure affect soybean internode elongation, mainstem node number, and pod number per plant. The Crop Journal. 2018; 6 (2):148-61.
- Appiah F, Asibuo JY, Kumah P. Physicochemical and functional properties of bean flours of three cowpea (*Vignaunguiculata* L. Walp) varieties in Ghana. 2011.
- Bita CE, Gerats T. Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. Frontiers in plant science. 2013; (4): 273.
- Burton GW, De Vane DE. Estimating heritability in tall fescue (*Festucaarundinacea*) from replicated clonal material. Agronomy journal. 1953; 478-81.
- Deva CR, Urban MO, Challinor AJ, Falloon P, Svitákova L. Enhanced leaf cooling is a pathway to heat tolerance in common bean. Frontiers in plant science. 2020; 11-19.
- Devasirvatham V, Gaur PM, Mallikarjuna N, Raju TN, Trethowan RM, Tan DK. Reproductive biology of chickpea response to heat stress in the field is associated with the performance in controlled environments. Field Crops Research. 2013;142:9-19.
- Gomez KA. Statistical procedures for agricultural research. John NewYork: Wiley and Sons. 1984.
- Hanson CH, Robinson HF, Comstock RE. Biometrical studies of yield in segregating populations of Korean lespedeza 1. Agronomy journal. 1956; 48(6):268-72.
- McDonald GK, Paulsen GM. High temperature effects on photosynthesis and water relations of grain legumes. Plant and soil. 1997; 196:47-58.
- Olorunwa OJ, Adhikari B, Brazel S, Bheemanahalli R, Barickman TC, Reddy KR. Waterlogging stress reduces cowpea (Vignaunguiculata L.) genotypes growth, seed yield, and

UNDER PEER REVIEW

quality at different growth stages: implications for developing tolerant cultivars under field conditions. Agricultural Water Management. 2023; 284:108336.

- Ortiz R, Sayre KD, Govaerts B, Gupta R, Subbarao GV, Ban T, Hodson D, Dixon JM, Ortiz-Monasterio JI, Reynolds M. Climate change: can wheat beat the heat?. Agriculture, Ecosystems and Environment. 2008; 126 (1-2):46-58.
- Timko MP, Singh BB. Cowpea, a multifunctional legume. In genomics of tropical crop plants. New York, NY: Springer New York. 2008: 227-258.
- Warrag MO, Hall AE. Reproductive responses of cowpea (*Vignaunguiculata* (L.) Walp.) to heat stress. I. Responses to soil and day air temperatures. Field Crops Research. 1984; (8)3-16.
- Yadav T, Nisha KC, Chopra NK, Yadav MR, Kumar R, Rathore DK, Soni PG, Manarana G, Tamta A, Kushwah M, Ram H. Weed management in cowpea-A review. International Journal of Current Microbiology and Applied Sciences. 2017; 6 (2):1373-85.

UNDER PEER REVIEW