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RESEARCH ARTICLE Agricultural Science Digest

Evaluation of *Desi* Chickpea (*Cicer arientinum* L.) Landraces for Heat Tolerance using Morpho-phenological Traits and Stress Tolerance Indices (STI)

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10.18805/ag.D-5902

ABSTRACT

Background: Chickpea is a globally important commercial crop and a key source of protein for vegetarian populations. Though chickpea was domesticated at least 3000 years ago, research into abiotic stress tolerance has been limited compared to cereals.

Methods: An experiment was conducted with a set of seventy-one genotypes of Desi chickpea (*Cicer arietinum* L.) to isolate high temperature tolerant genotypes using randomized block design (RBD) under two different sowing conditions (normal and late/ terminal heat stress) and two growing seasons (rabi-2017-18 and 2018-19) at the Pulses Research Station of Junagadh Agricultural University. The screening of heat tolerant genotypes was done based on nine morpho-phenological traits, stress tolerance indices and correlation amongst them.

Result: The heat tolerant genotypes of chickpea had less percentage of reduction in numbers of pods, seed yield per plant and 100-seeds weight. Five genotypes *viz*., ICC 4958, ICC 14595, ICC 8318, GG 4 and ICCV 92944 were identified as highly heat tolerant on the basis of HSI and YSR. These tolerant genotypes and screening criteria's can be of great importance to identify donor parents to develop new cultivars for the farmers growing chickpea in the heat prone regions.

Key words: Desi chickpea, Heat susceptibility index, Heat tolerance, Stress tolerance indices (STI).

INTRODUCTION

Chickpea productivity is constrained by several abiotic stresses and temperature is one of the most important determinants of crop growth over a range of environments and may limit chickpea yield (Basu *et al*., 2009). Rani *et al*. (2020) reviewed that chickpea production is limited by various abiotic stresses (cold, heat, drought, salt, *etc*.). Being a winter-season crop in northern south Asia and some parts of the Australia, chickpea faces low-temperature stress (0-15°C) during the reproductive stage that causes substantial loss of flowers and thus pods, to inhibit its yield potential by 30-40 per cent. In late-sown environments, chickpea faces high-temperature stress during reproductive and pod filling stages, causing considerable yield losses. Both the low and high temperatures reduce pollen viability, pollen germination on the stigma and pollen tube growth resulting in poor pod set. Chickpea also experiences drought stress at various growth stages; terminal drought, along with heat stress at flowering and seed filling can reduce yields by 40-45 per cent. Terminal drought and heat stresses are major constraints to chickpea production in warmer short-season environments as prevalent in Gujarat state. Also, the chickpea area under late-sown conditions is increasing, particularly in northern and central India, due to inclusion of chickpea in new cropping systems and intense sequential cropping practices. Heat stress at sowing directly affects crop germination and crop establishment. In Gujarat, many times sowing of chickpea is done late due to kharif crop like groundnut, cotton etc. under irrigated condition.

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How to cite this article: Chetariya, C.P., Pithia, M.S., Delvadiya, I.R., Pheirim, R., Soharu, A. and Dubey, N. (2024). Evaluation of *Desi* Chickpea (*Cicer arientinum* L.) Landraces for Heat Tolerance using Morpho-phenological Traits and Stress Tolerance Indices (STI). Agricultural Science Digest. DOI: 10.18805/ag.D-5902.

Submitted: 25-10-2023 **Accepted:** 10-01-2024 **Online:** 05-02-2024

Heat stress during the reproductive period is a major limitation in this situation too. Heat stress during the reproductive phase in chickpea is generally allied with lack of pollination, abscission of flower buds, decreases seed yield by reducing the number of seeds per plant and weight per seed, therefore reducing harvest index (Wang *et al*., 2006). The fertilization process is particularly sensitive to environmental stress, such as drought and heat that can reduce yields by up to 70 per cent (Jeffrey *et al*., 2021). In chickpea, longer the exposure during reproductive development to a high day temperature of 35°C, lower the yield. Most chickpea genotypes do not set pods when temperatures reach >35°C (Basu *et al*., 2009). In this situation there is an urgent need to have high yielding and early maturing chickpea varieties which can be grown under late sowing. For that systematic breeding programme is to be initiated to incorporate high temperature tolerance in a agronomically superior disease resistant varieties with better seed quality. Therefore, first step is to isolate high temperature tolerant genotypes suitable for late planting. Once identified the tolerant cultivars, it can benefits breeders as a donor in breeding programs. It may also be helpful in understanding phenological, physiological and biochemical mechanism of heat tolerance and find out key QTLs, heat stock proteins.

MATERIALS AND METHODS

Experimental materials, selection of site

The field experiment was conducted at the Pulses Research Station, Junagadh Agricultural University, Junagadh during *rabi* season of the year 2017-18 and 2018-19 to identify the high temperature tolerant genotypes of chickpea sown under two dates of sowing in a randomized block design with three replications. Seventy-one genotypes of *Desi* chickpea were collected from ICRISAT, Patencheru (Telangana) and Pulses Research Station, Junagadh Agricultural University, Junagadh. Each line was sown in a single row plot of 4.0 m length with a spacing of 45 × 10 cm. All the recommended crop production and protection practices were followed timely for the successful raising of crop. The detail sowing time and year of experimentation is given in the Table 1.

Geographically, Junagadh is situated at 21.52°N latitude and 70.47°E longitudes with an elevation of 60 meters above the mean sea level. The soil of the experimental site was medium black with pH 7.8. The climate of the area represents the tropical condition with semi-arid nature. The meteorological data for both the cropping seasons are presented in Fig 1.

Characters studied and observation procedure adopted

In each plot, five plants were randomly selected and tagged excluding terminal ones to minimize border effects. The nine observations recorded were days to 50 per cent flowering, days to maturity, reproductive phase duration, plant height (cm), numbers of branches, numbers of pods per plant, 100-seeds weight (g), SPAD value (chlorophyll content) and seed yield per plant (g) on these five randomly selected plants in each line and in each replication and their mean values were used for statistical analysis. Out of nine traits, first three were recorded on plot basis.

Heat susceptibility index (HSI)

Seed yield per plant as the most affected trait during pod filling stage (Stone, 2001) was used for the calculation of heat susceptibility index (HSI). The following formula and classification of Fisher and Maurer (1978) were used:

$$HSI = \frac{1 - [YL/YN]}{1 - [XL/XN]}$$

Where,

YL = Mean seed yield (g) of a line (genotype) under late sown conditions.

YN = Mean seed yield (g) of a line (genotype) under normal sown conditions.

XL= Mean seed yield (g) of all lines (genotype) under late sown conditions.

XN = Mean seed yield (g) of all lines (genotype) under normal sown conditions.

Classification of genotypes based on HSI.

HSI values	Classification
<0.50	Highly heat tolerant (HHT)
0.51-0.75	Heat tolerant (HT)
0.76-1.00	Moderately heat tolerant (MHT)
>1.00	Heat susceptible (HS)

Yield stability ratio (YSR)

The yield stability ratio (YSR) was calculated as per Lewis (1954).

$$YS = \frac{\text{Seed yield under late sown condition (g)}}{\text{Seed yield under normal sown condition(g)}} \times 100$$

Statistical analysis

The data recorded for various characters were statistically analyzed at the Computer Cell, Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh using IndoStat and R software.

RESULTS AND DISCUSSION

Impact of high temperature on crop depends on the coincidence of heat stress with sensitive phase of crop growth. Flowering and podding in chickpea are known to be very sensitive to change in external environment and drastic reduction in seed yield were observed when plants were exposed to high temperature (Wang *et al*., 2006; Bahuguna *et al*., 2012). Thus, it is important to determine the nature and extent of variability under different environmental conditions as provided by different temperatures by different dates of sowing. The exploitation of such variability should be aimed at developing temperature tolerant lines to grown in temperature prone areas. Therefore, seventy-one genotypes of chickpea were exposed to high temperature in late sowing to isolate temperature tolerant genotypes.

Screening for temperature tolerant genotypes

Many workers successfully used heat susceptibility index (HSI) along with yield stability ratio (YSR) as a powerful tool to identify heat tolerant genotypes. HSI and YSR are used in the present investigation and results obtained are presented in Table 2, 3 and 4. The per cent reduction in seed yield and its components comparing the highly heat tolerant and susceptible genotypes also calculated and presented in Fig 2 (Y-I), Fig 3 (Y-II) and Table 5 for pooled of both years. Results are described year wise and over the years (pooled) in forthcoming paragraphs.

According to HSI and YSR, chickpea genotype like ICC 4958, ICCV 92944, ICC 14595, ICC 1205 and GG 4 found highly heat tolerant in first year (Y-I: 2017-18) of evaluation. While highly susceptible genotype ICC 16374 had very high reduction in seed yield (4.68 g; 53.67%) and number of pods per plant (15.67; 33.87%). Reduction in 100-seed weight and reproductive phase duration was not too much in comparison to tolerant genotypes. In the second year (Y-II: 2018-19), ICC 6279, ICC 14595, ICC 8318, ICC 4958, GG 4, ICC 5383, ICCV 92944 and ICC 9895 recognized as highly heat tolerant chickpea genotypes. The highly heat susceptible genotype ICC 16374 had high percentage of reductions in respect to seed yield (61.48%), number of pods per plant (38.72%) and 100-seed weight (26.14%).

On the basis of pooled result of both years, out of the five highly heat tolerant genotypes, four genotypes *viz.*, ICC 4958, ICC 14595, GG 4 and ICCV 92944 were common in pooled results and individual results of year. ICC 4958 ranked first in heat tolerance by showing very less (0.03) HSI and very high YSR (91.46%) followed by ICC 14595 (0.34; 90.27%), ICC 8318 (0.40; 88.57%), GG 4 (0.42; 87.99%) and ICCV 92944 (0.43; 87.67%). Interestingly, all the above said genotypes registered less reduction in seed yield and its most important yield components in comparison to highly heat susceptible genotype (ICC 16374). Genotype ICC 16374 recorded 58.32, 36.86 and 2.47 per cent reduction in seed yield per plant, number of pods per plant and 100-seed weight, respectively.

Now, the next step is selection of superior heat tolerant genotypes, for which a suitable screening environment is

Table 1: The details of years wise sowing time.

Year of experiment	Detail of environment with sowing date	
Year-I (2017-18)	E_1: Normal sowing	(5th November, 2017)
	E_2: Late sowing	(3rd December, 2017)
Year-II (2018-19)	E_3: Normal sowing	(1st November, 2018)
	E_4: Late sowing	(2nd December, 2018)

Table 2: Grouping of 71 genotypes of chickpea based on heat susceptibility index (HSI) and yield stability ratio (YSR) during *rabi*-2017-18 (Y-I).

Groups as per STI	:	Genotypes identified
Highly heat tolerant genotypes (HIS: <0.50) (YSR: 84.64 to 91.85%)	:	ICC 4958, ICCV 92944, ICC 14595, ICC 1205, GG 4
Heat tolerant genotypes (HIS: 0.51-0.75) (YSR: 77.04 to 83.42%)	:	ICC 8318, ICC 8522, ICC 3362, ICC 12155, ICC 15510, ICC 2072, ICC 5613, ICC 3761, GG 5, ICC 14778, ICC 6293, ICC 10018, ICC 15612
Moderately heat tolerant genotypes (HIS: 0.76-1.00) (YSR: 68.84 to 75.10%)	:	ICC 6579, ICC 6816, ICC 1882, GJG 6, ICC 6874, ICC 2629, ICC 67, ICC 11121, ICC 14815, ICC 9895, ICC 9002, ICC 15614, ICC 6279, ICC 4418
Heat susceptible genotypes (HIS: >1.00) (YSR: 46.37 to 68.71%)	:	ICC 4657, ICC 6537, ICC 4363, ICC 10945, ICC 11198, ICC 14669, ICC 8950, ICC 637, ICC 13124, ICC 2884, ICC 14799, ICC 1083, ICC 1356, JG 16, ICC 2263, ICC 4495, GG 1, ICC 708, GJG 3, ICC 5383, ICC 13524, ICC 3631, ICC 2507, ICC 15618, ICC 5878, ICC 4182, ICC 4991, ICC 3325, ICC 506, ICC 2969, ICC 10685, ICC 15606, ICC 15868, ICC 11944, ICC 14831, Annegiri 1, ICC 10393, ICC 14402, ICC 16374

Table 3: Grouping of 71 genotypes of chickpea based on heat susceptibility index (HSI) and yield stability ratio (YSR) during *rabi*-2018-19 (Y-II).

Groups as per STI	:	Genotypes identified
Highly heat tolerant genotypes (HIS: <0.50) (YSR: 88.75 to 93.51%)	:	ICC 6279, ICC 14595, ICC 8318, ICC 4958, GG 4, ICC 5383, ICCV 92944, ICC 9895
Heat tolerant genotypes (HIS: 0.51-0.75) (YSR: 80.13 to 85.97%)	:	ICC 15510, ICC 8522, ICC 708, ICC 4363, ICC 15868, ICC 10018, ICC 637, ICC 14669, JG 16, ICC 6874, ICC 6816, GJG 6, ICC 14815, ICC 1205, ICC 5878, ICC 3761
Moderately heat tolerant genotypes (HIS: 0.76-1.00) (YSR: 73.60 to 79.62%)	:	ICC 2629, ICC 2072, ICC 2969, ICC 2507, ICC 4657, GJG 3, GG 5, ICC 13524, ICC 1083, ICC 14402, ICC 14778, ICC 2884, ICC 6579, ICC 1356
Heat susceptible genotypes (HIS: >1.00) (YSR: 38.48 to 73.39%)	:	ICC 3362, ICC 8950, ICC 506, ICC 4991, ICC 9002, ICC 3325, ICC 6537, ICC 12155, ICC 14799, ICC 14831, ICC 6293, ICC 67, ICC 11121, ICC 10945, ICC 1882, ICC 10685, ICC 4182, ICC 10393, ICC 4495, ICC 2263, ICC 11198, ICC 15618, ICC 5613, ICC 3631, ICC 15612, ICC 15606, ICC 4418, GG 1, ICC 11944, ICC 15614, Annegiri 1, ICC 13124, ICC 16374

Table 4: Grouping of 71 genotypes of chickpea based on heat susceptibility index (HSI) and yield stability ratio (YSR) from pooled data of both the years *rabi*-2017-18 (Y-I) and *rabi*-2018-19 (Y-II).

Groups as per STI	:	Genotypes identified
Highly heat tolerant genotypes (HIS: <0.50) (YSR: 87.67 to 91.46%)	:	ICC 4958, ICC 14595, ICC 8318, GG 4, ICCV 92944
Heat tolerant genotypes (HIS: 0.51-0.75) (YSR: 78.78 to 85.16%)	:	ICC 6279, ICC 8522, ICC 15510, ICC 1205, ICC 5383, ICC 9895, ICC 10018, ICC 3761, ICC 2072, ICC 6816
Moderately heat tolerant genotypes (HIS: 0.76-1.00) (YSR: 71.87 to 78.42%)	:	GG 5, GJG 6, ICC 4363, ICC 6874, ICC 14815, ICC 3362, ICC 14669, ICC 14778, ICC 2629, ICC 637, ICC 4657, ICC 12155, JG 16, ICC 6579, ICC 708, ICC 6293, ICC 15868, GJG 3
Heat susceptible genotypes (HIS: >1.00) (YSR: 41.69 to 71.06%)	:	ICC 13524, ICC 9002, ICC 1083, ICC 8950, ICC 2884, ICC 5878, ICC 1882, ICC 2507, ICC 67, ICC 6537, ICC 1356, ICC 11121, ICC 10945, ICC 14799, ICC 2969, ICC 506, ICC 5613, ICC 15612, ICC 4991, ICC 3325, ICC 11198, ICC 14402, ICC 2263, ICC 4495, ICC 4182, ICC 4418, ICC 14831, ICC 10685, ICC 15618, ICC 3631, ICC 10393, ICC 15614, GG 1,ICC 15606, ICC 11944, ICC 13124, Annegiri 1, ICC 16374

Table 5: Reduction in seed yield and its important components in highly heat tolerant and highly heat susceptible genotype(s) under late sown conditions (E_2 and E_4) in comparison to normal sown conditions (E_1 and E_3) in the *rabi*-2017-18 (Y-I) and *rabi*-2018-19 (Y- II) pooled.

Genotype	Seed yield per plant (g)				Number of pods per plant			
	NS	LS	Reduction	Reduction (%)	NS	LS	Reduction	Reduction (%)
Highly heat tolerant genotypes								
ICC 4958	14.04	12.84	1.20	8.55	49.43	46.37	3.06	6.19
ICC 14595	10.12	9.13	0.99	9.78	51.23	47.50	3.73	7.28
ICC 8318	13.53	11.99	1.54	11.38	70.00	62.43	7.57	10.81
GG 4	9.39	8.26	1.13	12.03	48.85	44.97	3.88	7.94
ICCV 92944	11.77	10.32	1.45	12.32	52.00	45.67	6.33	12.17
Highly heat susceptible genotype								
ICC 16374	10.70	4.46	6.24	58.32	60.07	37.93	22.14	36.86
		100-seed weight (g)				Reproductive phase duration		
ICC 4958	35.28	32.93	2.35	6.66	64.17	43.17	21.00	32.73
ICC 14595	22.58	21.37	1.21	5.36	56.33	41.33	15.00	26.63
ICC 8318	23.78	22.03	1.75	7.36	61.00	41.50	19.50	31.97
GG 4	19.58	18.83	0.75	3.83	49.67	44.33	5.34	10.75
ICCV 92944	24.78	23.58	1.20	4.84	52.17	48.00	4.17	7.99
ICC 16374	17.80	15.06	2.74	15.39	63.33	49.00	14.33	22.63

NS = Normal sown conditions (E_1 and E_3) pooled, LS = Late sown conditions (E_2 and E_4) pooled.

Table 6: Phenotypic (r_p) correlation coefficients of 10 characters with heat susceptibility index (HSI) in 71 genotypes of chickpea during *Rabi*-2017-18 (Y-I) and *Rabi*-2018-19 (Y-II).

Characters		Heat susceptibility index (HSI)	
		Rabi-2016-17 (Y-I)	*Rabi*-2018-19 (Y-II)
Days to 50 per cent flowering	r_p	0.0533	0.2662*
Days to maturity	r_p	0.0703	0.2497*
Reproductive phase duration	r_p	0.0074	-0.2150
Plant height (cm)	r_p	0.0235	-0.0382
No. of primary branches per plant	r_p	0.1769	0.0324
No. of pods per plant	r_p	-0.3903**	-0.0360
100-seed weight (g)	r_p	-0.4519**	-0.4434**
Seed yield per plant (g)	r_p	-0.6515**	-0.3525**
SPAD value	r_p	0.0290	-0.1838
Yield stability ratio (YSR)	r_p	-1.0000**	-1.0000**

*, ** Significant at 5 and 1% levels, respectively.

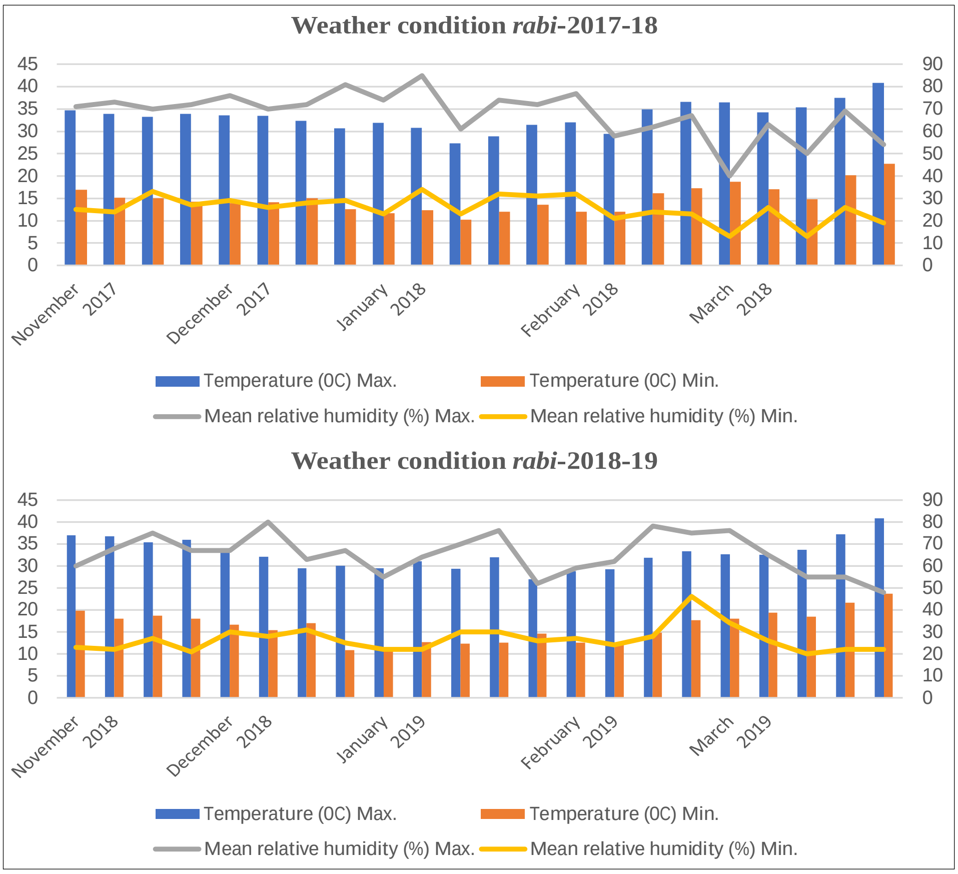

Fig 1: Weather conditions of *rabi* seasons 2017-18 (Y-I) and 2018-19 (Y-II).

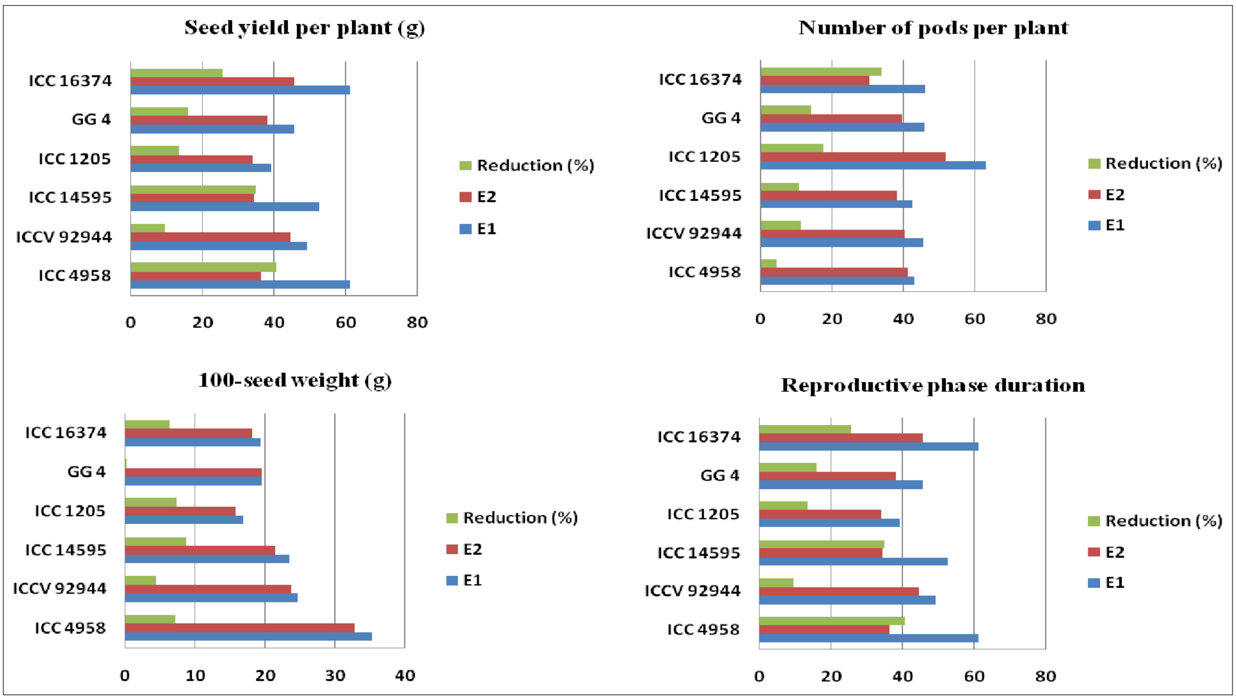

Fig 2: Per cent reduction in seed yield and its important components in highly heat tolerant and highly heat susceptible genotype(s) under late sown condition (E_2) in comparison to normal sown condition (E_1) in the *rabi*-2017-18 (Y-I).

essential. Many breeders/researchers (Devasirvatham *et al*., 2015; Kumar *et al*., 2017; Jha *et al*., 2021 and 2023; Sunil *et al*., 2021; Sachdeva *et al*., 2022, Tanwar *et al*., 2022 and Jain *et al*., 2023) used late planting to induce high level of heat stress from anthesis through grain filling period in chickpea. It proves cost effective and rapid method to screen a large population size within shorter period.

The chickpea genotype ICC 4958 produced the highest seed yield of 11.29, 14.39 and 12.84 g/plant in first, second and over years, respectively under late planting. It indicated that effect of heat stress was minimum on seed yield and its components like 100-seed weight and number of pods per plant. Reproductive phase duration was reduced under late sowing in this genotype but up to lesser extent in comparison to highly susceptible genotype ICC 16374. But ICC 4958 had capacity to complete life cycle rapidly without much more adverse effect on pre and post anthesis as evident from less reduction in number of pods per plant and 100-seed weight. Same was the situation of other above said heat tolerant genotypes. This genotype also contained good chlorophyll content at 75 DAS. ICCV 92944 was very early flowering and maturing genotype with comparatively long reproductive phase duration. This genotype also exhibited good potentiality to produce about 10.32 g seed yield per plant under late sowing. This clearly indicated the importance of conduction of study in proper environment.

Shukla *et al.* (2014) and Jha *et al.* (2023) also designated ICC 4958 as a heat tolerant genotype. This genotype also declared drought tolerant after several investigations conduct at ICRISAT (Anonymous, 1992) and other centers. Deep root system and bold seed size are the important morphological characters of this genotype. On the other hand, very early genotype ICC 92944 was also got recognition of heat tolerance from study conduct by (Kumar *et al*., 2013; Meshram, 2014; Hotti and Sadhukhan, 2018; Jha *et al*., 2021 and 2023). In case of highly heat susceptible genotype ICC 16374, our results are in agreement with of Krishnamurthy *et al.* (2011).

As higher temperatures after flowering leads to affects post anthesis, grain filling, pod formation, seed yield and ultimately induce forced maturity in chickpea Wang *et al.* (2006) and Mola *et al.* (2018). Reproductive phase duration was quite higher in normal sowing than late sowing. It indicated that genotypes completed their reproductive phase at a fast speed in late sowing. It means higher temperature forced the genotypes to complete their life cycle early. Singh (2016) and Yucel Derya (2018) also obtained reduction in seed yield and its component characters.

Association of tolerance indices (HSI and YSR) with seed yield and component traits

The phenotypic correlation coefficients were also worked out by taking heat susceptibility index (HSI) as a dependent character during both years *rabi* 2017-18 (Y-I) and *rabi* 2018-19 (Y-II) and presented in Table 6. The results of phenotypic correlation coefficient showed that yield stability ratio (rp = -1.0000 and rp = -1.0000), seed yield per plant (rp = -0.6515 and rp = -0.3525) and 100-seed weight (rp = -0.4519 and rp = -0.4434) had negative and highly significant phenotypic correlation with HSI during both the

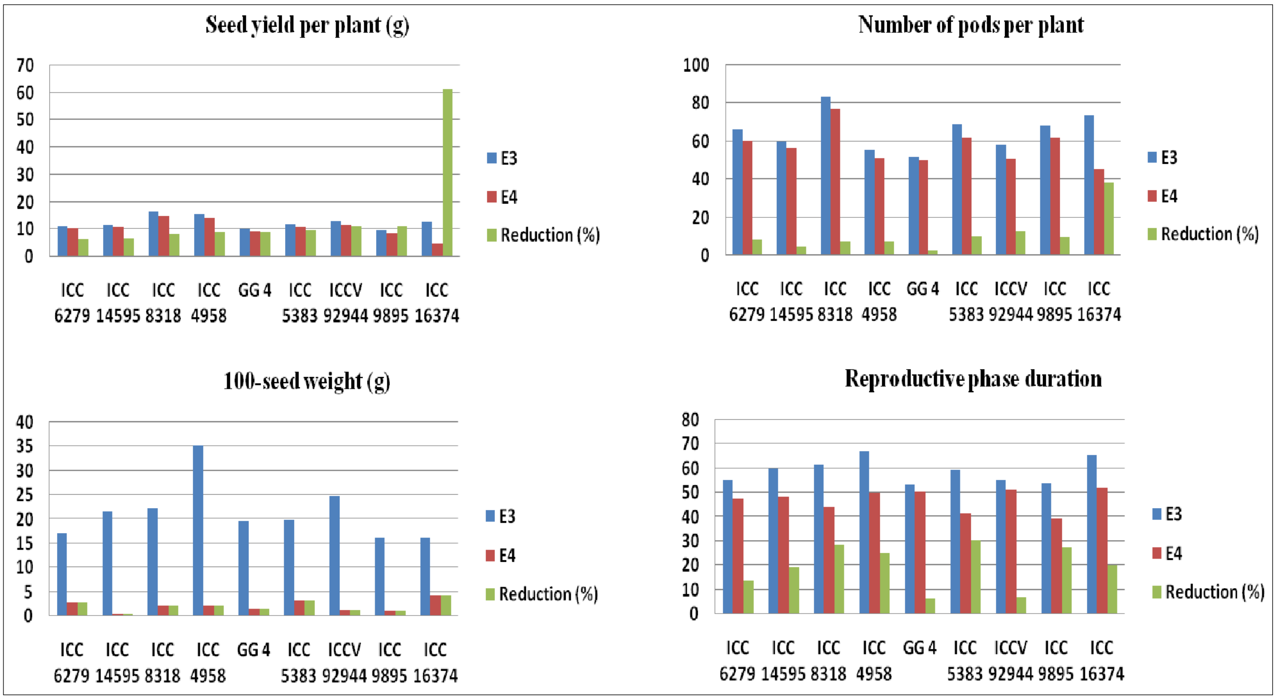

Fig 3: Per cent reduction in seed yield and its important components in highly heat tolerant and highly heat susceptible genotype(s) under late sown condition (E_4) in comparison to normal sown condition (E_3) in the *rabi*-2018-19 (Y-II).

years (Y-I and Y-II). While, number of pods per plant (rp = -0.3903) had negative and highly significant phenotypic correlation with HSI in Y-I. In Y-II, days to 50 per cent flowering (rp = 0.2662) and days to maturity (rp = 0.2497) had positive and significant phenotypic correlation with HSI.

Phenotypic correlation of seed yield and its components with heat susceptibility index (HSI) indicated that yield stability ratio, seed yield per plant and 100-seed weight had negative and highly significant correlation with HSI during both the years. This indicated that lower the HSI, higher the seed yield and 100-seed weight. While, number of pods per plant had negative had highly significant correlation with HSI in Y-I. It means number of pods was high in case of low values of HSI. Genotypes with lower HSI possessed a greater number of pods per plant. In Y-II, days to 50 per cent flowering and days to maturity had positive and significant correlation with HSI. Indirectly it suggested that early genotypes were more desirable as they had less HSI or high tolerance to high temperatures. Jha et al. (2021 and 2023) and Karimizadeh et al. (2021) also found negative correlation between HSI and seed yield per plant.

CONCLUSION

It's always challenging to predict climate and screen large numbers of genotypes by field experiments. The existence of narrow genetic base and cultivation of the crop in diverse climatic regions make it more difficult to identify the trait specific superior donor for thermos tolerant. From this study, it could be concluded that the genotypes with the lesser reduction in seed yield, number of pods per plant and hundred seeds weight has good potential for late sowing. The landraces completed life cycle earlier with shorted reproductive phase duration in late sown condition which means earliness is desirable trait for heat tolerance. Stress tolerance indices (YSR, HSI) can be quick, reliable, sustainable and cost-effective protocol to screen out from large number of germplasms in field screenings.

Conflict of interest

All authors declared that there is no conflict of interest.

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