Indian J. Genet. Plant Breed., (2024); 84(3): 415-424

https://doi.org/10.31742/ISGPB.84.3.12

ISSN: 0975-6906

www.isgpb.org

RESEARCH ARTICLE

Response of chickpea (*Cicer arietinum* L.) genotypes to high temperature under late sown conditions

Nagmi Praween*, Yogesh Kumar[1], Ravendra Singh Sikarwar, Syed Mohd Quatadah[2], P.S. Basu[1], Biswajit Mondal[1] and G.P. Dixit[1]

Abstract

High temperatures exceeding 35°C during the chickpea reproductive phase can significantly impact yield. This stress disrupts fertilization, leading to pod abortion and reduced seed set. To identify heat-tolerant genotypes for breeding programs, this study evaluated 113 diverse chickpea lines (varieties, landraces, exotic collections, and advanced breeding lines) under timely and late-sown conditions during the *rabi* seasons of 2019-20 and 2020-21. Ten heat tolerance indices were employed, including Yield Index (YI), Yield Susceptibility Index (YSI), Stress Tolerance Index (STI), and others. These indices exhibited significant variation among the genotypes and demonstrated both positive and negative correlations with seed yield under heat stress, highlighting their usefulness in identifying tolerant genotypes across different scenarios. While all genotypes experienced yield reduction under high temperatures, the extent of the reduction varied considerably among the genotypes. Based on a comprehensive analysis of heat stress indices and other statistical parameters, chickpea genotypes IPC17-129, IPC18-131, IPC17-143, IPC16-136, and IPC17-351 were identified as heat-tolerant and recommended for use as parents in breeding programs aimed at developing heat-resistant chickpea varieties.

Keywords: Chickpea, heat stress, seed yield, heat tolerance indices, PCA, bilot, clustering

Introduction

Chickpea (*Cicer arietinum* L.), also known as gram, Bengal gram, Egyptian pea, garbanzo bean, is a self-pollinated, annual diploid (2n = 2x = 16) species (Cobos et al. 2007) with a genome size of 738 Mb (Varshney et al. 2013). Chickpea (*Cicer arietinum* L.) is a self-pollinated true diploid (2n = 2x = 16) cool season leguminous crop that ranks second among foodgrain legumes in the world after the common bean. The chickpea is a member of the genus *Cicer*, Tribe *Cicereae* and family *Fabaceae*. The center of origin of chickpeas dates back to the southeastern region of Turkey (Ladizinsky and Adler 1976; Singh and Ocampo 1997). It is grown in more than 50 countries across all continents and is mainly cultivated in the rainfed ecology of the Indian subcontinent, the Mediterranean region, the West Asian and NorthAmerican region, the East-African region and Latin America (Rani et al. 2020). The chickpea has 34 perennial wild species and 9 annual species. Among nine annual species, *Cicer arietinum* is the only cultivated species worldwide (Singh et al. 2008; Harlan and de Wet 1971).

There are two types of cultivated chickpeas *kabuli* and *desi*. *Desi* (microsperma) type plant has anthocyanin pigmentation on stems, pink flowers, and a wild range colored and thick seed coat. The *kabuli* (macrosperma) types plant lacks of anthocyanin pigmentation on a stem, white flowers, white or beige-colored seeds with a ram's head shape, and smooth seed surface with thin seed coat (Moreno and Cubero 1978). Additionally, an intermediate type with

Department of Genetics and Plant Breeding, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior 474 002, Madhya Pradesh, India.

[1]ICAR-Indian Institute of Pulses Research, Kanpur 208 024, Uttar Pradesh, India.

[2]Department of Genetics and Plant Breeding, Faculty of Agriculture, Deen Dayal Upadhyaya 273 009, Gorakhpur, Uttar Pradesh, India.

***Corresponding Author:** Nagmi Praween, Department of Genetics and Plant Breeding, Rajmata VijayarajeScindia Krishi Vishwavidyalaya, Gwalior 474 002, Madhya Pradesh, India, E-Mail: nagmi0802@gmail.com

How to cite this article: Praween N., Kumar Y., Sikarwar R.S., Quatadah S.M., Basu P.S., Mondal B. and Dixit G.P. 2024. Response of chickpea (*Cicer arietinum* L.) genotypes to high temperature under late sown conditions. Indian J. Genet. Plant Breed., **84**(3): 415-424.

Source of support: Nil

Conflict of interest: None.

Received: Jan. 2024 **Revised:** June 2024 **Accepted:** July 2024

© The Author(s). 2024 Open Access This article is published by the Indian Society of Genetics & Plant Breeding, NASC Complex, IARI P.O., Pusa Campus, New Delhi 110 012; Online management by www.isgpb.org

pea-shaped seeds of local importance is recognized in India. Desi type predominates in production and accounts for 85%, while kabuli accounts for 15% of world chickpea production. Chickpea is grown in 15.004 million hectares (M ha) area across the world, with a productivity of 1058 kg/ha and a production of 15.87 million Tones (MT) worldwide (FAO, 2020). India is the largest chickpea-producing country with a share of 73.78% (10.943 M ha) in the area and 73.45% (11.91 MT) production of chickpeas in the world. In India, chickpea production reached 13.75 MT from a cultivated area of 10.91 M ha with productivity of 1260 kg/ka (Anonymous 2023). It plays a pivotal role in India's pulse production, contributing nearly 50% to the total pulse output. The major chickpea-producing states in the country include Maharashtra, which contributes 25.97% of national production, followed by Madhya Pradesh (18.59%), Rajasthan (20.65%), Gujarat (10.10%), and Uttar Pradesh (5.64%) (Sharma and Sharma 2020).

Temperature badly affects the normal growth and development of chickpeas. In India, the chickpea area reduced by 4.3 M ha in northern and north-western India, which has cooler long-season environments and increased by 4.3 M ha in central and southern India, which has relatively warmer and short-season environments (Anonymous 2021). Thus, there has been a considerable increase in chickpea cultivation in areas that are prone to heat stress during the reproductive phase of crop development. Global warming is expected to increase the temperatures by up to 1.8 to 4°C by the end of this century, affecting chickpea yields. With the increase of per 1°C temperature during the reproductive phase, a minimum 53 kg yield loss has been recognized by the researcher (Karla et al. 2008). It is essential to identify the most sensitive stages of the reproductive phase to high temperatures. The heat stress (>35^{0}C) at flowering and podding stages results in drastic reductions in seed yield. Exposure to heat stress (>35^{0}C) at flowering and podding in chickpeas is known to result in drastic reductions in seed yields (Summerfield et al. 1984; Wang et al. 2006; Devasirvatham et al. 2012). Yield penalty due to heat stress in south east Asia increasing. Collaborative efforts of ICRISAT and ICAR-IIPR, Kanpur identified some potential sources of heat stress tolerance lines *viz.,* ICC1205, ICC637, ICC3362, ICC4991, ICC8950, ICC14346, JG 14 and ICC15614 based on field screening (Krishnamurty et al. 2011; Upadhaya et al. 2011 and Gaur et al. 2012).

Developing varieties suited to cultivation under high-temperature stress conditions and screening of high-temperature stress tolerance diverse genotypes various physiological, biochemical and plant breeding measures (Cossani and Reynolds 2012, Reynolds and Langridge 2016) are been used in past, but in recent times for screening and isolation of heat tolerance genotypes from a diverse population a very effective measure i.e., various heat tolerance indices are in practice. These heat tolerance indices are constructed based on the grain yield performance of genotypes under heat stress and control conditions (Jha et al. 2018).

In this study we adopted different physiological indices based on seed yield under timely sown and late sown conditions to identify heat tolerance lines with respect to trait-specific checks. We took a diverse panel with test ABLs derived from the breeding program for terminal drought and heat for evaluation along with some heat tolerance checks.

Materials and methods

Experimental materials

A set of 113 diverse chickpea genotypes, including heat tolerant checks (DCP92-3, ICC1205, ICC7110, JG 14 and ICC15614), 13 landraces, 3 accessions from ICRISAT, Hyderabad and 92 advanced breeding lines from ICAR-Indian Institute of Pulses Research (IIPR), Kanpur were collected (Table 1). The experiment was carried out at ICAR-IIPR Kanpur (26°29' N, 80°16'E and 130m). The genotypes were evaluated during Rabi 2019-20 and Rabi 2020-21 (Table 2). The weather data were collected from ICAR-Indian Institute of Pulses Research, Kanpur of two crop growing season.

Field layout and experimental design

The experimental material was planted under timely sown (TS) conditions on 1st November, 2019 and late sown (LS) conditions (hear stress) on 17th December 2019, and the harvesting of TS trial was done on 20th April 2020, whereas LS trial on 2nd May 2020. The same trials were repeated next year in which the TS trial was planted on 10th November 2020 and harvested on 27th April 2021, whereas the planting of LS trial was done on 24th December 2020 and the material was harvested on 7th May 2021. All the trials were conducted in Augmented design with 5 blocks along with 5 checks all replicated in 5 blocks. The seeds of each genotype were sown in 4 meters row length and row to row spacing was maintained 30 cm for both the trials. Plot yield and other biometrical data were recorded selecting and tagging 10 randomly selected plants for each genotype under both conditions.

Eight following heat tolerance indices were estimated and measured by using seed yield (g) under non-stress and stress-sown conditions during 2019-20 and 2020-21 for the identification and selection of heat tolerant genotypes. Various heat-tolerant genotypes were selected on the basis of the estimated value of stress indices, correlation between seed yield and stress indices, principal component analysis of different traits and cluster analysis.

Yield index (YI) = YS/$\hat{Y}$s (Gavuzzi et al. 1997); Yield stability index (YSI) = YS/YP (Bouslama and Schapaugh 1984); Stress tolerance index (STI) = (YP × YS)/$\hat{Y}$p2 (Fernandez 1992); Mean

Table 1. Details of chickpea genotypes (113) used in the study

S.No.	Genotype	Originating centre	Parentage	S.No.	Genotype	Originating centre	Parentage
1	BDG 72	IARI, New Delhi	(BG256/E100YM)/BG 256	58	IPC 17-129	IIPR, Kanpur	GNG 1581/ICC 7110
2	DCP 92-3 (C)	IIPR, Kanpur	Selection from local Germplasm	59	IPC 17-141	IIPR, Kanpur	C 8/HC 5
3	GCP 105	GAU, Junagadh	ICCL 84224/Annegeri 1	60	IPC 17-143	IIPR, Kanpur	IPCK 02-29/ILWC 245
4	GG 2	GAU, Junagadh	JG 1258/BDN9-3	61	IPC 17-166	IIPR, Kanpur	KWR 108/ICC 4958
5	GNG 663	Sriganganagar	GNG 16/GNG 146	62	IPC 17-174	IIPR, Kanpur	IPC 08-57/ILWC 245
6	GNG 1958	Sriganganagar	GNG 365/SAKI9516	63	IPC 17-185	IIPR, Kanpur	GNG 1581/ICC 14778
7	ICC 1205 (C)	ICRISAT, Hyderabad	Traditional cultivar / landrace collected from UP	64	IPC 17-189	IIPR, Kanpur	ICC 1164/ICC 10945
8	ICC 4958	ICRISAT, Hyderabad	Advanced improved line (JGC1) collected from MP	65	IPC 17-196	IIPR, Kanpur	ICC 1205/ICC 8522
9	ICC 7110 (C)	ICRISAT, Hyderabad	Traditional cultivar / landrace collected from Lebanon	66	IPC 17-207	IIPR, Kanpur	JG 11/PA 1108
10	ICC 15614 (C)	ICRISAT, Hyderabad	Traditional cultivar / landrace collected from Tanzania	67	IPC 17-213	IIPR, Kanpur	IPC 06-11/DCP 92-3
11	IPC 12-31	IIPR, Kanpur	Katila/ICCV10	68	IPC 17-245	IIPR, Kanpur	GNG 1581/ICC 15614
12	IPC 12-211	IIPR, Kanpur	Katila/ICCV 10	69	IPC 17-249	IIPR, Kanpur	IPC 06-11/ILWC 249
13	IPC 14-56	IIPR, Kanpur	JG2001-4-1/KWR 108	70	IPC 17-253	IIPR, Kanpur	IPC 06-11/PA 1108
14	IPC 14-133	IIPR, Kanpur	Phule G 05/IPC 17-29	71	IPC 17-256	IIPR, Kanpur	IPC 08-57/ILWC 245
15	IPC 15-12	IIPR, Kanpur	GNG 1581/ILWC 141	72	IPC 17-303	IIPR, Kanpur	JG16/ICC 1205
16	IPC 15-16	IIPR, Kanpur	IPC 09-50/IPC 07-88	73	IPC 17-308	IIPR, Kanpur	HC 5/ILWC 21
17	IPC 15-35	IIPR, Kanpur	KWR 108/ICC7110	74	IPC 17-318	IIPR, Kanpur	ICC 1205/JG 03-14-16
18	IPC 15-39	IIPR, Kanpur	KWR 108/ICC7110	75	IPC 17-351	IIPR, Kanpur	IPC 06-11/IPC 04-52
19	IPC 15-57	IIPR, Kanpur	HC 5/ILWC 115	76	IPC 17-354	IIPR, Kanpur	IPCK 02-29/ILWC 21
20	IPC 15-95	IIPR, Kanpur	HC 5/ILWC 115	77	IPC 17-358	IIPR, Kanpur	GNG 469/ILWC 21
21	IPC 15-108	IIPR, Kanpur	HC 5/EC 556270	78	IPC 17-361	IIPR, Kanpur	IPC 09-50/IPC 07-88
22	IPC 15-113	IIPR, Kanpur	GNG 1581/ILWC 21	79	IPC 17-373	IIPR, Kanpur	IPC 08-57/WR 315
23	IPC 15-132	IIPR, Kanpur	GNG 1581/ILWC 237	80	IPC 17-377	IIPR, Kanpur	IPC 06-11/ICC 96030
24	IPC 15-146	IIPR, Kanpur	GNG 1581/ILWC 21	81	IPC 18-28	IIPR, Kanpur	IPC 06-88/ILWC 179
25	IPC 15-147	IIPR, Kanpur	BG 256/IPC 04- 52	82	IPC 18-37	IIPR, Kanpur	IPC 06-88/ILWC 179
26	IPC 15-165	IIPR, Kanpur	GNG 469/ILWC 21	83	IPC 18-38	IIPR, Kanpur	HC 5/DCP 92-3
27	IPC 15-185	IIPR, Kanpur	IPC 06-11/ILWC 21	84	IPC 18-40	IIPR, Kanpur	IPC06-11/PA 1108
28	IPC 15-202	IIPR, Kanpur	KWR 108/ILWC 115	85	IPC 18-48	IIPR, Kanpur	ILWC 21/IPC 08-57
29	IPC 16-06	IIPR, Kanpur	IPC 2009-50/IPC 07-88	86	IPC 18-52	IIPR, Kanpur	IPC 06-88/ILWC 179
30	IPC 16-15	IIPR, Kanpur	GNG 1581/ILWC 115	87	IPC 18-55	IIPR, Kanpur	GNG 1581/IPC 04-52
31	IPC 16-25	IIPR, Kanpur	KWR 108/ICCC 15614	88	IPC 18-56	IIPR, Kanpur	IPC 06-11/ICC 96030
32	IPC 16-26	IIPR, Kanpur	IPC 06-27/JG 03-14-16	89	IPC 18-59	IIPR, Kanpur	GNG 1581/IPC 04-52
33	IPC 16-27	IIPR, Kanpur	ICARDA 37125	90	IPC 18-63	IIPR, Kanpur	IPC 10-63/IPC 08-57

34	IPC 16-39	IIPR, Kanpur	IPCK 02-29/ILWC 21	91	IPC 18-69	IIPR, Kanpur	KWR 108/ICC 1205
35	IPC 16-52	IIPR, Kanpur	IPCK 02-29/ILWC 21	92	IPC 18-80	IIPR, Kanpur	GNG 1581/IPC 04-52
36	IPC 16-53	IIPR, Kanpur	BPM/IPC 06-11	93	IPC 18-90	IIPR, Kanpur	GNG 1581/IPC 04-52
37	IPC 16-95	IIPR, Kanpur	HC 5/JG 315	94	IPC 18-117	IIPR, Kanpur	IPC 12-122/IPC 10-63
38	IPC 16-136	IIPR, Kanpur	ILWC 21/IPC 08-57	95	IPC 18-121	IIPR, Kanpur	JG 62/JG 03-14-16
39	IPC 16-184	IIPR, Kanpur	BG 256/JG 03-14-16	96	IPC 18-129	IIPR, Kanpur	IPC 08-11/ICC 7110
40	IPC 16-231	IIPR, Kanpur	KWR 108/ICC 1205	97	IPC 18-131	IIPR, Kanpur	GNG 1581/ICC 15614
41	IPC 16-236	IIPR, Kanpur	IPC 06-11/ICC 96030	98	IPC 18-132	IIPR, Kanpur	IPC 06-127/ILWC 245
42	IPC 17-04	IIPR, Kanpur	JG 16/IPC 08-57	99	IPC 18-136	IIPR, Kanpur	IPC 08-11/ICC 14778
43	IPC 17-10	IIPR, Kanpur	KWR 108/EC 600098	100	IPC 18-150	IIPR, Kanpur	IPC 06-127/ILWC 245
44	IPC 17-21	IIPR, Kanpur	JG 16/IPC 08-57	101	IPC 18-154	IIPR, Kanpur	BG 212/JG 03-14-16
45	IPC 17-35	IIPR, Kanpur	JG 315/JG 03-14-16	102	IPC 18-168	IIPR, Kanpur	JG 16/ICC 92944
46	IPC 17-37	IIPR, Kanpur	IPCK 04-29/ILWC 179	103	JG 11	JNKVV, Jabalpur	(PG5/Narsinghpur/ ICCC37]ICCX-860263-BF-BP-91BP
47	IPC 17-47	IIPR, Kanpur	IPC 09-50/ICC 14778	104	JG 14 (C)	JNKVV, Jabalpur	[(GW5/7//P327)/// ICCL83149]
48	IPC 17-53	IIPR, Kanpur	JG 315/JG 03-14-16	105	JG 74	JNKVV, Jabalpur	Selection from Genetic Stock
49	IPC 17-54	IIPR, Kanpur	IPC 08-57/ICC 1205	106	JG 130	JNKVV, Jabalpur	[(PG5/Narsinghpur bold)/JG 74]
50	IPC 17-67	IIPR, Kanpur	GNG 469/ICC5434	107	K 850	CSAUT, Kanpur	Banda local/Etah bold
51	IPC 17-70	IIPR, Kanpur	IPC 08-57/PA 1108	108	NBeG 3	Nandyal	A 1/ICC 4958
52	IPC 17-71	IIPR, Kanpur	ICC 1205/ICC 10945	109	PG 5 (Vishwas)	MPKV Rahuri	B 110/N31
53	IPC 17-78	IIPR, Kanpur	IPC 08-57/PA 1108	110	RSG888 (Anubhav)	RARI, Durgapura	RSG 44/E100YM
54	IPC 17-88	IIPR, Kanpur	IPC 06-127/ILWC 145	111	RSG 991 (Aparna)	RARI, Durgapura	K 850/RSG515
55	IPC 17-102	IIPR, Kanpur	WR 315/IPC 10-116	112	Sadabahar	CSAUT, Kanpur	Hima/L 245
56	IPC 17-110	IIPR, Kanpur	ICC 5434/ICC 1205	113	Vaibhav	IGKV, Raipur	Selection from Germplasm of ICC91106
57	IPC 17-114	IIPR, Kanpur	IPC 08-57/ICC 1164				

productivity (MP) = (Yp + Ys)/2 (Rosielle and Hamblin 1981); Geometric mean productivity (GMP) = $\sqrt{(YS \times YP)}$ (Fernandez 1992); Tolerance Index (TOL) = YP-YS (Rosielle and Hamblin 1981); Mean relative performance (MRP) = $(YS/\hat{Y}s) + (YP/\hat{Y}p)$ (Ramirez and Kelly 1998); Heat susceptibility Index (HIS) = $(1-(Ys/Yp))/SI$ where $SI = 1-(\hat{Y}s / \hat{Y}p)$ (Fischer and Maurer 1978; Hossain et al. 1990), and Per cent yield Reduction (PYR %) = $(YP-YS)/YP \times 100$ (Farshadfar and Javadinia 2011)

Where, YP and YS are the seed yield individual genotypes under non-stress and stress sown conditions. In contrast, $\hat{Y}P$&$\hat{Y}S$ are the mean seed yield of all genotypes under non-stress and stress-sown conditions.

Results and discussion

Analysis of variance of pooled data

The pooled data over the years for both trials were used for the estimation of analysis of variance. The combined ANOVA exhibited that the seed yield under timely sown (non-stress) and late sown (Stress) conditions varied significantly (p = 0.001) among the genotypes, test entries and test Vs check for most of the heat tolerance indices (Table 2). The pooled ANOVA was exhibited that the high temperature plays a significant role in the growth and development of genotypes and seed yield production. The Mean Sum of

Table 2. Pooled ANOVA for seed yields Timely sown (YP) and Late sown (Stress condition) (YS) and nine heat tolerance indices of chickpea genotypes

Source of Variation	DF	Mean Sum of Square											
		YP	YS	YI	YSI	STI	MP	GPM	MPR	TOL	HSI	RSI	PYR (%)
Genotypes	112	15053.42**	672.05**	658.84**	783.39**	7648.02**	6747.39**	8064.83**	1562.16**	1726.56**	714.15**	510.36**	8140.3**
Check entries	4	90.026	17.072	9.059	1007.008	4.0002	63.8	89.08	0.0077	0.0096	0.0073	6.005	0.0203
Test vs. Check	1	5458.68**	1386.24**	539.64**	77533.76**	1329.11**	2160.128**	5551.22**	484.09**	1966.5**	1062.68**	2113.35**	7450.13**
Test entries	107	1148.26**	4458.75*	1158.62**	1174.93**	3265.82*	4443.48**	6660.31**	1167.54**	2204.67**	3240.61**	1109.07**	4870.05**
Block	3	0008.21	0.2002	0.0560	4.0025	8.0085	0.2001	69.093	41.23	1011.27	50.006	15.61	0.0342
Error	12	12.76	3.00-2	4.0008	3.11	15.3	419.23	1117.3	2121.1	4447.98	118.7	0.046	45.03

YI = Yield index, YSI = Yield stability index, STI = Stress tolerance index, MP = Mean productivity, GMP = Geometric mean, MRP = Mean relative performance, TOL = Tolerance index, HIS = Heat susceptibility index, RSI = Relative stress index, and PYR = Per cent yield reduction

Square (MSS) value of all the heat tolerance indices was varied significantly for seed yield. The chickpea genotypes expressed variations when evaluated under heat-stress environments (Gaur 2013).

Heat tolerance indices

In the present investigation, the different heat tolerance indices *viz.*, YI, YSI, STI, MP, GMP, MPR, TOL, HIS, RSI and PYR (%) were estimated through Microsoft Excel 2019, based on seed yield under timely sown (non-stress) and late sown (stress) trials (Table 3). The highest value of YI, STI, MP, GMP and MRP were recorded by the genotype IPC17-351 and showed the most heat stress tolerant, productive and stable among all genotypes under both the cropping conditions (time sown and late sown). The chickpea genotype IPC17-47 has recorded the lowest value for these stress tolerance indices and observed poor performance with less stability under late sown (stress) conditions. The highest value of YSI, TOL, RSI and PYR (%) were recorded by IPC18-136 and considered as heat stress susceptible chickpea genotype due to low seed yield under late sown conditions as compared to timely sown conditions. The chickpea genotype IPC17-129 was exhibited a lower value of YSI, TOL, RSI and PYR (%) with less yield reduction percentage (%) under late sown trail as compared to timely sown trial, and it considered as most heat stress tolerant genotypes. The chickpea genotypes IPC17-129 (6.71%), IPC18-131 (7.46%), IPC17-143 (8.73%), IPC16-136 (9.05%) and IPC17-351 (9.16%) were observed very less seed yield reduction percentage (PYR) over tolerant checks (ICC1205, ICC15614 and JG14) and stress susceptible check (DCP92-3) under late sown trial, and it may be considered as heat tolerant genotypes due less yield difference under both cropping condition (Table 3). The heat tolerance indices in chickpea were reported for identification of heat tolerant and susceptible chickpea genotypes (Devasiratham et al. 2012; Sabaghnia and Janmohammadi 2014; Jha et al. 2018; Varshney 2009).

In the current investigation, chickpea genotype IPC18-136 was found the most heat susceptible based on the higher value of YSI, TOL, RSI and PYR. Genotype IPC17-351 was exhibited heat tolerant with maximum value of YI, STI, MP and GMP. The selection of genotypes based on higher value of MP is always creating difficulties for the identification of tolerant genotypes under non-stress and stress condition. Based on heat tolerance indices, the MP value should be avoided for the selection of heat stress tolerant genotypes (Lamba et al. 2023). Yield reduction % (PYR) is also an important heat tolerance estimates for the selection of heat tolerance chickpea genotypes under stress sown environments (Jha et al. 2014, 2017; Poarch 2006). The genotypes IPC17-129 (6.71%), IPC18-131 (7.46%), IPC17-143 (8.73%), IPC16-136 (9.05%) and IPC17-351 (9.16%) were exhibited very less reduction percentage in seed yield under high temperature condition, and considered as heat

Table 3. Descriptive statistics for seed yield/plot (g) under timely sown and late sown trials conducted during 2019-20 and 2020-21

Descriptive statistics	YP	YS	YI	YSI	STI	MP	MRP	GMP	TOL	HSI	RSI	PYR (%)
Minimum	521.00	303.00	0.54	0.48	0.24	422.25	1.19	405.06	55.16	0.21	1.57	6.71
Maximum	1160.50	1033.25	1.84	0.93	1.72	1085.35	3.22	1084.10	530.94	1.63	3.06	51.98
Mean	825.72	562.23	1.00	0.68	0.70	693.98	2.00	679.83	263.50	1.01	2.20	32.15
Range	639.50	730.25	1.30	0.45	1.48	663.10	2.02	679.04	475.78	1.42	1.48	45.27
Standard Deviation	139.00	133.25	0.24	0.09	0.27	129.13	0.39	130.02	86.33	0.28	0.27	9.02
Standard Error	13.08	12.54	0.02	0.01	0.03	12.15	0.04	12.23	8.12	0.03	0.03	0.85

tolerant genotypes. The maximum value of YI, STI, MP and GMP is to prefer for identification of superior genotypes perform well under stress as well as non-stress environments (Kumar et al. 2023; Dorostkar et al. 2015; Sio-Se Mardeh et al. 2006).

Correlation coefficient analysis between seed yield and estimated nine heat tolerance indices

The correlation coefficient between seed yield and different heat tolerance indices were calculated over the year under timely sown (non-stress) and late sown (stress) conditions (Table 4). The seed yield under non-stress (YP) and stress (YS) conditions is significantly correlated (0.800**), which indicates it may be used to identify high-yielding genotypes under non-stress and stress condition. The seed yield under non-stress condition (YP) was exhibited positive (+Ve) and highly significant correlation with most of the heat tolerance indices *viz.*, YI (0.800**), STI (0.908**), MP (0.951**), MRP (0.929**), GMP (0.931**) and TOL (0.376*), but showed negative (-Ve) and non-significant correlation with HIS, RSI and PYR (%) (Table 4). Therefore, selection based on these indices will enhance seed yield under non-stressed conditions. Similarly, absolute correlation was exhibited with yield index (YI), it may be used for the identification of heat tolerant genotypes under stress condition. The yield stability (YS) is also positive correlated with YSI (0.714**), STI (0.969**), MP (0.946**), MPR (0.965**) and GMP (0.963**) but negative and significantly correlated with TOL (-0.256), HIS (-0.714**), RSI (-0.669**) and PYR % (-0.714**). The selection based on YSI, STI, MP, GMP and MPR heat tolerance indices will enhance the seed yield, but decrease seed yield when considering TOL, HIS, RSI and PYR under stress conditions (Table 5). The most heat tolerance indices are positively correlated with YI, YSI, STI, MP, MRP and GMP under both non-stress and stress condition, but negatively correlated with TOL, HIS, RSI and PYR. Based on these, genotypes IPC17-129 (6.71 %), IPC18-131 (7.46 %), IPC17-143 (8.73 %), IPC16-136 (9.05%) and IPC17-351 (9.16) are considered as heat tolerant.

To determine the relationship between different heat tolerance indices and to calculate indices for comparing genotypes, a PCA bi-plot has been constructed using PC1 and PC2. The angle between two variables of stress indices is to determine the correlation between them (Yan and Rajcan 2002). If angle between two variable vectors is obtuse, it reflects the association between two variables is positively correlated, and acute angle represents two variables is negatively correlated. The perpendicular position of two vectors were showed that no correlation between the variable vector. In current investigation, YP and YS were positively associated with YI, YSI, MP, MRP, GMP and STI, while TOL, HIS, RSI and PYR showed negative correlation with YP and YS.

In the present investigation, the seed yield under timely sown (YP) and late sown (YS) conditions was positive and significantly correlated (0.800**). Earlier, the significantly positive correlation between seed yield (YP and YS) and the estimated heat tolerance indices was reported by Kamrani et al. (2017) and Lamba et al. (2023), indicating some test entries performing well under both conditions. Heat tolerance indices *viz.,* YI, YSI, STI, MP, MRP and GMP are positively correlated with seed yield under timely and late sown conditions, and it means that the heat indices have direct affects on seed yield under non-stress and stress environment. Selection under stress condition would be beneficial for the identification of high yielding genotypes under non-stress and stress environments (Sabaghnia and Janmohammadi 2014).

Principal component, bi-plot and cluster analysis

It is a statistical approach that can be used to analyze high-dimensional data and capture the important information. It is done by transforming original data into lower-dimensional space while collating highly correlated variables together. The

Table 4. Estimated of correlation coefficient between seed yield/plot (g) under timely sown and late sown conditions of chickpea genotypes and its calculated heat tolerance indices

Parameters	YP	YS	YI	YSI	STI	MP	MRP	GMP	TOL	HSI	RSI
YS	0.800**										
YI	0.800**	1.000**									
YSI	0.159	0.714**	0.714**								
STI	0.908**	0.969**	0.969**	0.529**							
MP	0.951**	0.946**	0.946**	0.454**	0.988**						
MRP	0.929**	0.965**	0.965**	0.509**	0.993**	0.998**					
GMP	0.931	0.963**	0.963**	0.505**	0.993**	0.998**	1.000				
TOL	0.376*	-0.256	-0.256	-0.846**	-0.033	0.070	0.007	0.012			
HSI	-0.159	-0.714**	-0.714**	-0.680**	-0.529*	-0.454	-0.509*	-0.505*	0.846**		
RSI	-0.114	-0.669**	-0.669**	-0.981**	-0.481	-0.406	-0.461	-0.460	0.849**	0.981**	
PYR (%)	-0.159	-0.714**	-0.714**	-0.900**	-0.529*	-0.454	-0.509*	-0.505*	0.846**	1.000**	0.981

Table 5. Clustering of elite chickpea genotypes using different heat stressindices

Cluster	Total no. of genotypes	Name of the genotypes
Cluster-I	18	BGD72, GCP105, IPC16-136, IPC17-143, IPC18-131, IPC17-129, K850, Vaibhav, GNG2, IPC16-53, ICC7110, RSG888, RSG991, PG5, IPC15-147, JG130, IPC16-321, IPC16-26
Cluster-II	28	IPC12-131, IPC18-136, IPC14-56, DCP92-3, IPC15-12, IPC15-146, IPC17-04, IPC15-185, IPC18-38, IPC15-16, IPC17-141, IPC17-67, IPC17-57, IPC17-245, IPC17-253, IPC16-95, IPC18-59, IPC16-25, IPC16-52, IPC18-90, IPC17-207, IPC17-249, IPC18-80, IPC16-236, IPC17-88, IPC18-117, IPC18-121
Cluster-III	34	IPC12-211, IPC18-132, NBeG 3, IPC15-202, IPC16-39, IPC14-133, IPC16-184, IPC17-166, IPC17-354, IPC17-10, IPC17-114, IPC17-110, IPC18-55, IPC18-28, IPC17-303, IPC17-373, IPC18-154, IPC17-21, IPC17-70, IPC18-168, IPC17-213, IPC17-377, IPC15-39, IPC16-15, IPC17-358, IPC17-256, IPC15-113, SADABAHAR, IPC18-52, IPC16-27, IPC18-40, IPC15-165, IPC17-308, IPC18-129
Cluster-IV	24	IPC15-95, IPC17-37, IPC16-06, IPC17-102, IPC17-78, IPC17-35, IPC17-54, IPC18-150, IPC17-185, IPC17-361. IPC18-37, IPC18-69, IPC18-56, IPC18-63, IPC15-132, IPC18-48, IPC17-53, IPC17-174, IPC17-71, IPC17-196, IPC15-108, IPC17-318, IPC17-47, IPC17-189.
Cluster-V	7	GNG663, ICC4958, JG74, ICC1205, ICC15614, GNG1958 and JG11
Cluster-VI	2	IPC17-351 and JG14

principal component analysis (PCA) would pick eleven heat tolerance-related heat indices *viz.*, YP, YS, YI, YSI, STI, MP, MRP, GMP, TOL, HST, RSI and PYR. It could make it easier to visualize and understand data. In present study, screening of heat stress tolerant genotypes based on seed yield under non-stress and stress conditions (YP and YS), 12 different heat tolerance indices were used for PCA analysis. Out of 12 principal components (PC), first two PCs were exhibited with >1.0 eigen value and showed maximum variation (96.50). The first and second PC was contributed 70.73 and 28.7 First PC has showed the highest positive correlation with YP (0.25), YS (0.34), YSI (0.34), STI (0.24), MP (0.32), MRP (0.31), GMP (0.32) and TOL (0.32), while it exhibited negative correlation with HIS, RSI and PYR. The second PC was exhibited a positive (+Ve) correlation only with YP, YS, YSI, STI and MP.

To compare the correlation between genotype and different estimated thermo-tolerance index, a bi-plot has

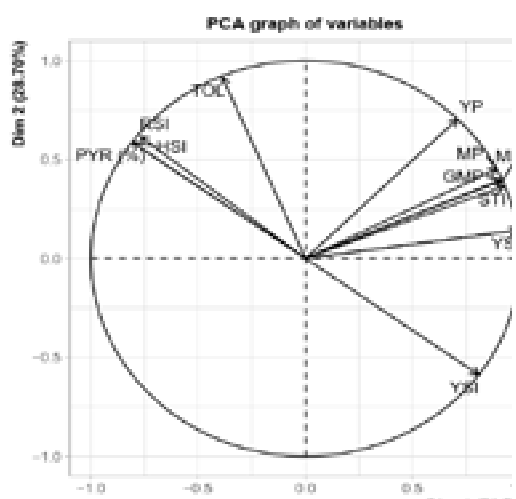

Fig. 1. Circular variable plot showing contribution of individual indices toward total variability

been created using PC1 and PC2. Each plot shows the correlations between the original variables and first two PCs. Each point represents the correlations between an original variable and two PCs. The circular variable PCA graph represents the contribution of each individual heat tolerance indices through vector length towards variability (Fig. 1). The correlations with the first PC are plotted on the horizontal axis, while correlations with the second PC are plotted on the vertical axis. The last two visualization approaches, biplot and attributes importance, can be combined to create a single biplot, where attributes with similar cos2 scores will have similar colors. Bi-plot constructed using PCA estimated between different heat tolerance indices variables and individual genotypes (Fig. 2). The heat indices MP, MRP, GMP, STI, RSI, HIS and PYR exhibited the high cos2 attributes (green color). However, the heat indices YSI displayed the medium cos2 attributes (blue color) while YP, YI and TOL represented low cos2 attributes. Based on this, genotypes JG14 (Check), ICC1205 (Check), ICC15614 (Check), JG11, BGD72, IPC17-129, GNG663, JG74, IPC18-131, IPC17-351, IPC16-136 and IPC17-143 were observed more stable and exhibited less yield reduction as compared to timely sown (non-stress) trial because PC1 shown highest value than their corresponding PC2. Genotypes IPC18-136, IPC12-31, IPC15-35, IPC18-129, IPC17-47, IPC15-165, IPC17-189, DCP92-3 (Check), IPC18-38, IPC17-78, IPC17-303 is considered to be less performer under stress condition as compared to non-stress sown condition, just because PC2 represented highest value as compared to PC1.

The PCA has been used to calculate the percentage contribution of the major components and stress indices to the total variance using seed yield under non-stress and stress environments and heat stress tolerance index. Many researchers used PCA in place of correlation coefficient estimates and suggested that it would provide better information for selecting heat stress tolerance and susceptible genotypes under stress cropping environment (Nouri et al. 2011; Talebi et al. 2009). In addition to reducing the number of characters that contribute to the highest percentage overall variations, PCA reveals the relationship between all traits simultaneously. Previous investigation has drawn the conclusion that components having >1 eigenvalue contribute more to the total variation as compared to the average value. Consequently, it provides the framework for choosing components. In this study, the yield was the primary variable and the basis for analysis. The PC1 and PC2 both are positively associated with YP, YS, YSI, STI, MP and MRP. Therefore, PC1 and PC2 both could be considered as potential heat-tolerant component for seed yield under stress and non-stress conditions.

Euclidean distance is considered for cluster analysis. Based on twelve different heat tolerance indices viz., YP, YS, YSI, STI, MP, MRP, GMP, TOL, HIS, RSI and PYR. Clustering of genotypes was performed. Six clusters were observed. Cluster VI and I exhibited the potentially heat tolerant lines with less yield penalty with respect to heat tolerant checks. High-yielding check JG 14 was clustered with ABLs IPC 17-35. The clustering pattern shows the maximum genotypes in cluster-III (34), followed by cluster II (28), cluster-IV (24) and cluster-I (18) (Table 5). Cluster-VI comprises only two

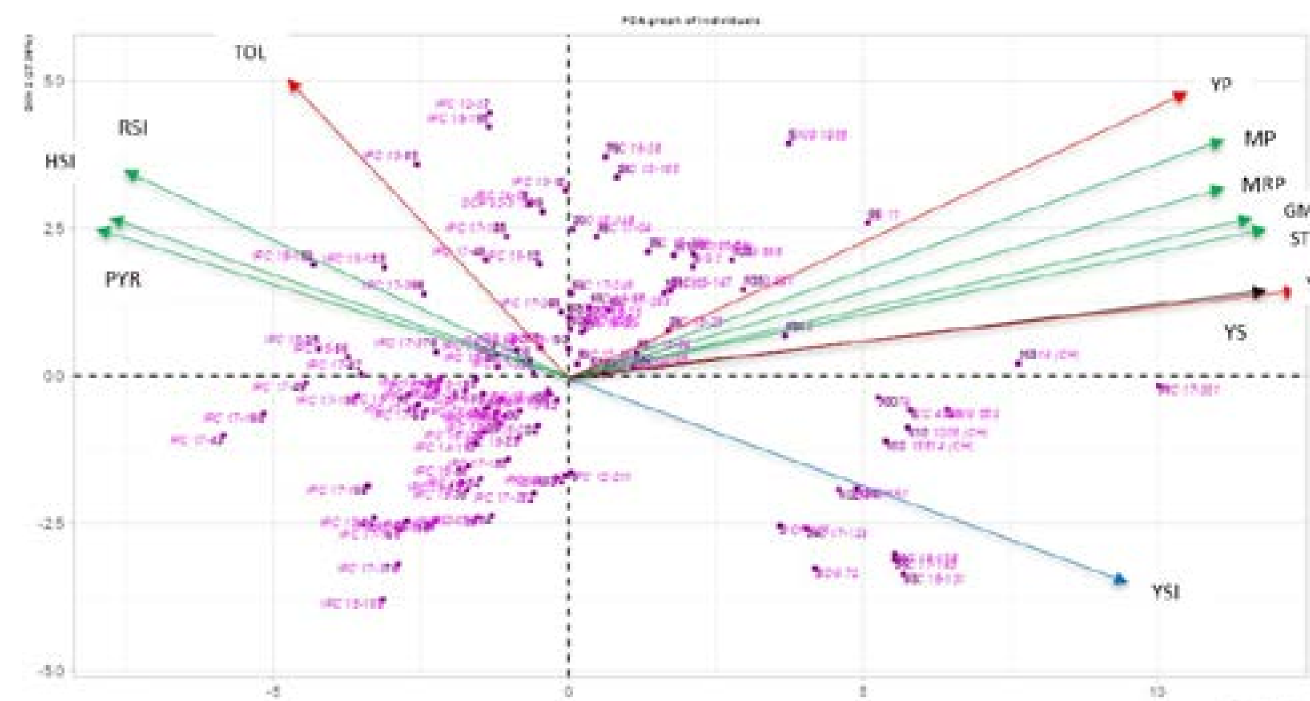

Fig. 2. Bi-plot constructed using PCA estimated, between different heat tolerance indices variables and individual genotypes

genotypes (IPC17-351 and JG14) and observed more heat stress tolerance. In present investigation, IPC17-143, IPC17-129 and IPC18-131 genotypes were found heat tolerant and comes in Cluster-I along with pre-identified heat tolerant lines viz., BGD72, GCP105, K850, VAIBHAV and ICC7110.

Authors' contribution

Conceptualization of research (NP, GPD, YK, RSS); Designing of the experiments (NP, YK, GPD, DB); Contribution of experimental materials (GPD, RSS); Execution of field/lab experiments and data collection (NP, RSS); Analysis of data and interpretation (NP, GPD, SMQ, RSB, BM); Preparation of the manuscript (NP, YK, GPD, RSS).

References

Anonymous. 2021. Department of Agriculture Cooperation, Ministry of Agriculture & Farmers Welfare. Growth in area, production and productivity of major pulses in India, Ministry of Agriculture and Farmer Welfare Report, 2021.

Anonymous. 2023. Directorate of Economics and Statistics (DES), Ministry of Agriculture & Farmers Welfare, Government of India. 2023. Annual Report on total cultivated area, production and productivity of chickpea during 2023,

Bouslama M. and Schapaugh W.T. 1984. Stress tolerance in soybean, part 1: Evaluation of three screening techniques for heat and drought tolerance. Crop Sci., **2**: 933–937.

Cobos M.J., Rubio J., Fernández-Romero M.D., Garza R., Moreno M.T., Millán T. and Gil J. 2007. Genetic analysis of seed size, yield and days to flowering in a chickpea recombinant inbred line population derived from a *Kabuli* × *Desi* cross. Ann. Appl. Biol., **151**: 33–42.

Cossani C.M. and Reynolds M.P. 2012. Physiological traits for improving heat tolerance in wheat. Plant Physiol., **160**: 1710–18.

Devasirvatham V., Tan D.K.Y., Gaur P.M., Raju T.N. and Trethowan R.M. 2012. High temperature tolerance in chickpea and its implications for plant improvement. Crop Pasture Sci., **63**: 419–428.

Dorostkar S., Dadkhodaie A. and Heidari B. 2015. Evaluation of grain yield indices in hexaploid wheat genotypes in response to drought stress. Archives of Agronomy and Soil Science, **61**: 397–413.

Farshadfar E. and Javadinia J. 2011. Evaluation of chickpea (*Cicer arietinum* L.) genotypes for drought tolerance. Seed Plant Improv. J., **27**(4): 517–537.

Fernandez G.C.J. 1992. Effective selection criteria for assessing plant stress tolerance. *In*: Proceedings of the international symposium on adaptation of vegetables and other food crops in temperature and water stress (Ed., Kuo C.G.). AVRDC Publication: Tainan, Taiwan: Shanhua: Chapter, **25**: 257–270.

Fischer R.A. and Maurer R. 1978. Drought Resistance in Spring Wheat Cultivars, I. Grain Yield Response. Aust. J. Agric. Res., **29**: 897–912.

Food and Agriculture Organization. 2020. FAO statistical database on annual production and area of wheat around the globe.

Gaur P.M. 2013. Climate change and heat stress tolerance in chickpea in Climate Change and Plant Abiotic Stress Tolerance (eds., N. Tuteja and S.S. Gill) Wiley-VCH Verlag GmbH & Co. Pp. 837-856. DOI: 10.1002/9783527675265

Gaur P.M., Jukanti A.K. and Varshney R.K. 2012. Impact of genomic technologies on chickpea breeding strategies. Agronomy, **2**: 199-221.

Gavuzzi P. Rizza F., Palumbo M., Campanile R.G., Ricciardi G.L. and Borghi B. 1997. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canad. J. Plant Sci., **77**: 523–531.

Hossain A.B.S., Sears A.G., Cox T.S. and Paulsen G.M. 1990. Desiccations tolerance and its relationship to assimilate partitioning in winter wheat. Crop Sci., **30**: 622–627.

Janmohammadi M., Abdoli H., Sabaghnia N., Esmailpour M. and Aghaei A. 2018. The effect of high temperature on pod set and seed yield of chickpea (*Cicer artietinum* L.) in mediterranean climate. Acta. Univ. Agric. Silvic. Mende. l Brun., **66**: 49-60.

Jha U.C. Chaturvedi S.K. Bohra A., Basu P.S., Khan M.S. and Barh D. 2014. Abiotic stresses, constraints and improvement strategies in chickpea. Plant Breed., **133**(2): 163–78.

Jha U.C., Bohra A. Jha R. and Parida S. 2017. Integrated 'omics' approaches to sustain major global grain legume productivity under heat stress. Plant Breed., **136**(4): 437–59.

Jha U.C., Jha R., Singh N.P., Shil S. and Kole P.C. 2018. Heat tolerance indices and their role in selection of heat stress tolerant chickpea (*Cicer arietinum*) genotypes. Indian J. agric. Sci., **88**(2): 260–267.

Kalra N., Chakraborty D., Sharma A., Rai H.K., Jolly M., Chander S., Kumar P.R., Bhadraray S., Barman D., Mittal R.B., Lal M. and Sehgal M. 2008. Effect of temperature on yield of some winter crops in northwest India. Curr. Sci., **94**: 82–88.

Kamrani M., Hoseini Y. and Ebadollahi A. 2017. Evaluation for heat stress tolerance in durum wheat genotypes using stress tolerance indices. Arch. Agron. Soil Sci., **64** (1): 38-45.

Krishnamurthy L., Gaur P.M., Basu P.S., Chaturvedi S.K., Tripathi S., Vadez V., Rathore A., Varshney R.K. and Gowda C.L.L. 2011. Large genetic variation for heat tolerance in the reference collection of chickpea (*Cicer arietinum* L.) germplasm. Plant Genet. Resour., **9**(1): 59–69.

Kumar S., Kumar H., Gupta V., Kumar A., Singh S.M., Kumar M., Singh A.K., Panwar G.S., Sujit Kumar S., Singh A.K. and Kumar R. 2023. Capturing agro-morphological variability for tolerance to terminal heat and combined heat-drought stress in landraces and elite cultivar collection of wheat. Front. Plant Sci., **14**: 1406.

Ladizinsky G. and Adler A. 1976. Genetic relationships among the annual species of *Cicer* L. Theor. Appl. Genet., **48**: 197-203.

Lamba K., Kumar M., Singh V., Chaudhary L., Sharma R., Yashveer S. and Dalal M.S. 2023. Heat stress tolerance indices for identification of the heat tolerant wheat genotypes. Scientific Report, **13**: 10842.

Moreno M. and Cubero J.I. 1978. Variation in *Cicer arietinum* L. Euphytica, 27: 465-485.

Nouri A., Etminan A., Teixeira da Silva J.A. and Mohammadi R. 2011. Assessment of yield, yieldrelated traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. durum Desf.). Aust. J. Crop Sci., **5**: 8.

Poarch T.G. 2006. Application of stress indices for heat tolerance screening of common bean. J. Agron. Crop Sci., **192**: 390-394.

Ramirez-Vallejo P. and Kelly J.D. 1998. Traits related to drought resistance in common bean. Euphytica, **99**: 127–136.

Rani A., Devi P., Jha U.C., Sharma K.D., Siddique K.H. and Nayyar H. 2020. Developing climate-resilient chickpea involving physiological and molecular approaches with a focus on temperature and drought stresses. Front. Plant Sci., **10**: 1759.

Reynolds M. and Langridge P. 2016. Physiological breeding. Current Opinion Plant Biol., **31**: 162–72.

Rosielle A.A. and Hamblin J. 1981. Theoretical aspects of selection for yield in stress and non-stress environment. Crop Sci., **21**: 943–946.

Sabaghnia N and Janmohammadi M. 2014. Evaluation of selection indices for drought tolerance in some chickpea (*Cicer arietinum* L.) genotypes. Acta Technologica Agricultuarae. DOI: 10.2478/ata-2014-0002.

Sharma S. and Sharma R. 2020. Chickpea economy in India. *In:* Chickpea: Crop wild relatives for enhancing genetic gains. Academic Press: Pp. 225-250.

Singh K.B. and Ocampo B. 1997. Exploitation of wild *Cicer* species for yield improvement in chickpea. Theor. Appl. Genet., **95**: 418-423.

Sio-Se Mardeh A., Ahmadi A., Poustini K. and Mohammadi V. 2006. Evaluation of drought resistance indices under various environmental conditions. Field Crops Res., **98**(2-3): 222–229.

Summerfield R.J., Hadley P., Roberts E.H., Minchin F.R. and Rawsthrone S. 1984. Sensitivity of chickpea (*Cicer arietinum* L.) to hot temperatures during the reproductive period. Exp. Agric., **20**: 77–93.

Talebi R., Fayaz F. and Naji A.M. 2009. Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.). General Appl. Plant Physiol., **35**: 64–74.

Upadhaya H.D., Dronavalli N., Gowda C.L.L. and Singh S. 2011. Identification and evaluation of chickpea germplasm for tolerance to heat stress. Crop Sci., **51**: 2079-2094.

Varshney R.K. 2009. Screening for drought tolerance in selected chickpea (*Cicer arietinum* L.) germplasm in semi-arid areas of Kenya. *In:* Proc. Annual Research Meetings of CGIAR generation challenge program chickpea annual research meeting, 20-23rd September 2009. Bamako, Mali.

Varshney R.K., Song C., Saxena R.K., Azam S. et al. 2013. Draft genome sequence of chickpea (*Cicer arietinum* L.) provides a resource for trait improvement. Nature Biotechnol., **31**(3): 240-246.

Wang J., Gan Y.T., Clarke F. and McDonald C.L. 2006. Response of chickpea yield to high temperature stress during reproductive development. Crop Sci., **46**: 2171–2178.

Yan W. and Rajcan I. 2002. Biplot analysis of test sites and trait relations of soybean in Ontario. Crop Sci., **42**(1): 11–20. doi: 10.2135/cropsci2002.1100.