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Heat tolerance indices and their role in selection of heat stress tolerant chickpea (*Cicer arietinum*) genotypes

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ABSTRACT

Given the current scenario of global climate change, high temperature stress is appearing as a major challenge limiting crop productivity including chickpea (*Cicer arietinum* L.). Evidences of significant yield loss in chickpea due to high temperature stress encountering during reproductive stage has been recorded. Therefore, to sustain chickpea productivity, identification of heat stress (HS) tolerant chickpea via recruiting 'breeder's friendly' selection criteria based on yield traits under field condition is urgently needed. In our current study, we evaluated 78 chickpea genotypes (including 3 checks) in 5 blocks in augmented design under normal and late sown condition during 2015-16. Various HS tolerance indices, viz. mean productivity (MP), geometric mean productivity (GMP), yield index (YI), tolerance index (TOL), stress susceptibility index (SSI) and superiority measure (SM) were employed for identifying chickpea genotype based on grain yield under normal and HS conditions. Based on the important selection indices, viz. YI, MP, GMP and SSI the following genotypes RVG 203, RSG 888, JAKI 9218, GNG 469, IPC 06-11 showed higher to moderate heat tolerance. Positive and high significant correlation of Yp with Ys, MP, YI, GMP, SSI and TOL was recorded. Likewise, Ys showed positive and high significant correlation with MP and GMP. While, YI indicated significant and high positive correlation with MP and GMP, but it showed negative correlation with SSI. Importantly, MP and GMP both showed high and positive correlation with SSI and TOL, respectively. Importantly, principal component analysis lowered all the six indices into 2 components PC1 explaining 61.9% and PC2 explaining 37.1% of total variation. While, 3-D scatter plot analysis grouped all the genotypes into four groups. Likewise, considering cluster analysis, four distinct clusters were generated based on above-mentioned various indices. Towards this end, correlation analysis, 3-D scatter plot and cluster analysis explained that the most effective and efficient selection indices for identifying heat tolerant genotype are MP, YI, GMP and SSI.

Key words: Cluster analysis, Heat tolerance, Principal component analysis, Tolerance indices

Globally chickpea (*Cicer arietinum* L.) ranks the third most important pulses crop next to common bean (*Phaseolus vulgaris* L.) and pea (*Pisum sativum* L.) (FAO 2013). Annually 14.2 Mt chickpea is harvested from 14.8 m ha area across the globe with an average productivity of 0.96 t/ha (FAO 2014). Importantly, India remains the highest chickpea producing country across the globe (FAO 2014). As an important member of legume species, chickpea offers plant based dietary protein and essential micronutrients to human food chain and serves an important component of global food as well as protein security (Graham and Vance 2003). Given the adversely changing climate, high temperature stress is appearing as global threat to crop production including grain legume crops (Lobell and Field 2007, Jha *et al.* 2014a, 2014b, 2017). In this context, increasing evidences of alteration in phenology and significant yield loss due to HS has been recorded in chickpea grown in tropical and sub tropical region (Krishnamurthy *et al.* 2011). Significantly, drought and HS cause losses up to 1.3 billion US $ in chickpea as estimated by Ryan (1997). Similarly, yield loss up to 53 kg/ha under HS has been recorded in chickpea grown in India (Kalra *et al.* 2008). To date, limited genetic resources for HS tolerance in chickpea have been reported (Devasirvatham *et al.* 2012, Devasirvatham *et al.* 2013, Jha 2014b, Jha *et al.* 2015a, 2015b). In order to screen heat tolerant crop genotypes, several physiological and plant breeding based parameters are available (Cossani and Reynolds 2012, Reynolds and Langridge 2016). Equally, yield based indices are also essential for comparing crop performance under non stress and stress condition and thus enable in selecting superior genotype (Poarch, 2006). Here

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we investigated the relevance of breeder friendly important yield based indices for identification of superior chickpea genotype under HS.

MATERIALS AND METHODS

The present study was carried out at main farm of Indian Institute of Pulses Research (IIPR), Kanpur. The experimental material constituted 78 chickpea genotypes including three checks. The experiment was conducted in the year 2015 and 2016 under normal sown and late sown condition in augmented design in 5 blocks each contained 18 genotypes including 3 heat tolerant checks (ICC 1205, ICC 4958 and ICC 92944) (Devasirvatham *et al.* 2012, Devasirvatham *et al.* 2013). The crop was sown in the second week of November 2105 (non HS) and the late sown crop was sown in second week of January 2016 (HS). Each genotype was sown in two rows having 4×0.3 m^2 plot size. Same agronomic package and practices (fertilizer and irrigation) were followed under both stressed and non stressed conditions. Plot yield data and other various morpho-physiological data were recorded from 10 randomly selected plants for each genotype under the both conditions.

Six heat tolerance indices including geometric mean productivity (GMP), yield index (YI), mean productivity (MP), stress susceptibility index (SSI), tolerance index (TOL), superiority measure (SM) were calculated by the given formulae.

Geometric mean productivity (GMP) = Ypi ×Ysi (Ramirez and Kelly 1998)

Yield index (YI) =Ysi/ Ys (Gavuzzi *et al.* 1997)

Mean productivity (MP) = (Ypi+Ysi)/2 (Hossain *et al.* 1990)

Stress susceptibility index (SSI) = (1-(Ysi/Ypi))/SI (Fischer and Maurer 1978)

Tolerance index (TOL) = Ypi-Ysi (Rosielle and Hamblin 1981)

Ysi and Ypi are the mean grain yield of individual genotype in HS and non HS condition; SI is stress intensity, where SI=1- (Ys/Yp); Ys=total mean grain yield of all genotypes in HS condition; Yp= total mean grain yield of all genotypes in non HS condition.

Superiority measure $Pi = [\sum_{j=1}^{n} (\mathrm{Xij} - \mathrm{Mj})^2 / 2n]$ (Lin and Binns 1988)

Where, n = number of environments; X_{ij} = Grain yield of ith genotype at the jth environment, and M_j = Grain yield of the genotype with maximum yield at jth environment.

Correlation analysis was conducted in R statistical package. Principal component analysis (PCA) and hierarchical cluster analysis were performed by running SAS, version 9.3. While, biplot analysis and three dimensional plots drawing were performed by 'R', versions 2.15.

RESULTS AND DISCUSSION

Significant genetic variability for various morpho-physiological traits was recorded for the given set of seventy eight genotypes grown under both HS and normal conditions (not shown here). Genetic variability obtained from the given genotypes based on various heat tolerance indices were given in Figs 1,2,3. Considering YI as an important heat tolerance index, RVG 203 (1.28), Pusa 240 (1.71), JAKI 9218 (1.22), GNG 469 (1.28), RSG 888 (1.44) genotypes (Table 1) showed higher YI value than the check ICC 92944 (1.2). Importantly, YI index as an important selection parameter for drought tolerance in chickpea (Sabaghnia and Janmohammadi 2014) and in rice have been reported (Khan and Dhurve 2016). Likewise, considering MP as an important selection parameter for heat tolerance RVG 203 (227.5), RSG 888 (271.5), Rajas (286), IPC 06-11 (280.6) genotypes exhibited higher value than the check ICC 92944 (217.5). In the context, this index was implicated for selecting drought tolerance genotype in rice and in wheat (Khan and Dhurve 2016, Anwar *et al.* 2011). Importantly, considering GMP as an important selection index for heat tolerance, IPC 06-11(280.62), GNG 469 (236.6), RSG 888 (261.3), RVG 203 (221.3), Rajas (268.3) showed higher value than the check ICC 92944 (211.07). Similarly based on this parameter both drought and heat tolerant genotypes were identified in common bean (Poarch 2006, Ramirez-

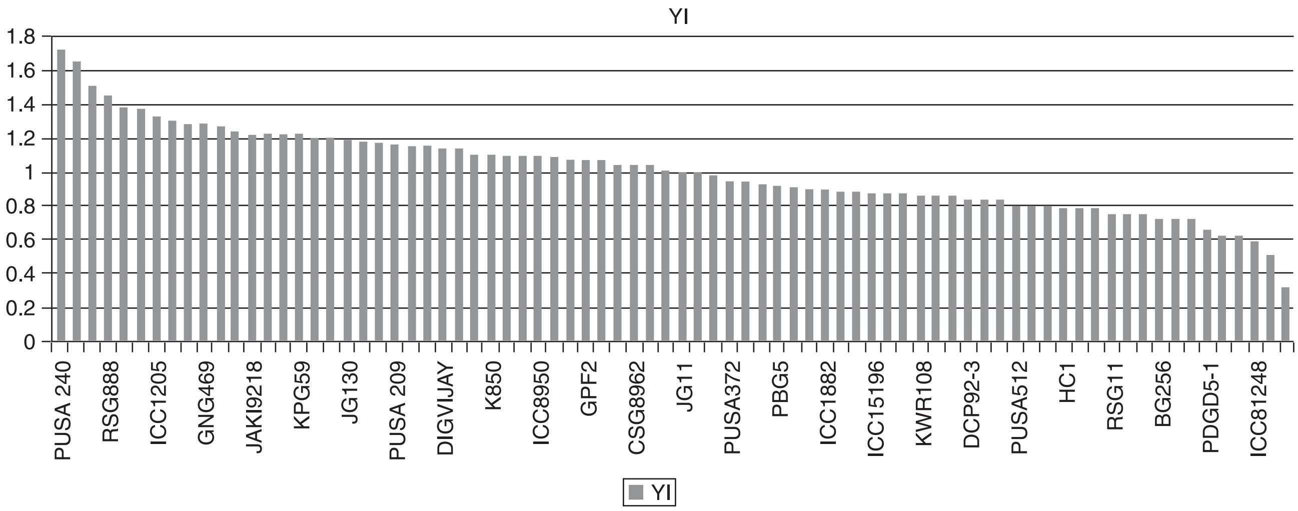

Fig 1 Variability of YI of different chickpea genotypes as a function of non stress and HS condition.

Table 1 Mean comparison of heat tolerance indices and grain yield (g) of chickpea genotypes under both non stress (Yp –non stress) and heat stress (Y*s*) condition

Genotype	Yp	Ys	YI	MP	GMP	SSI	TOL	SM	Group
BGD72	215	120	0.87	167.5	160.62	0.92	95	100.82	1
BG256	230	98	0.71	164	150.13	1.2	132	55.125	1
GCP101	269	142	1.04	205.5	195.44	0.98	127	60.5	2
KATILA	265	108	0.79	186.5	169.17	1.23	157	32	1
Avrodhi	262	109	0.79	185.5	168.99	1.22	153	35.28	1
BGM413	364	145	1.06	254.5	229.74	1.25	219	1.62	3
CSG8962	245	141	1.03	193	185.86	0.88	104	88.445	2
PUSA372	240	129	0.94	184.5	175.95	0.96	111	79.38	2
JG11	259	137	1	198	188.37	0.98	122	66.125	2
PDG3	225	110	0.8	167.5	157.32	1.07	115	74.42	1
PDG4	295	118	0.86	206.5	186.57	1.25	177	18	1
CHAFFA	295	135	0.98	215	199.56	1.13	160	29.645	2
JG16	301	118	0.86	209.5	188.46	1.27	183	14.58	1
KWR108	285	118	0.86	201.5	183.38	1.22	167	24.5	1
RVG203	280	175	1.28	227.5	221.36	0.78	105	87.12	2
JG130	255	160	1.17	207.5	201.99	0.78	95	100.82	2
GPF2	270	145	1.06	207.5	197.86	0.96	125	62.72	2
JAKI9218	235	167	1.22	201	198.1	0.6	68	142.805	2
RSG11	225	102	0.74	163.5	151.49	1.14	123	64.98	1
PUSA261	185	128	0.93	156.5	153.88	0.64	57	162	1
VISWAS	289	151	1.1	220	208.9	1	138	49.005	2
K850	270	150	1.09	210	201.25	0.93	120	68.445	2
PUSA547	295	116	0.85	205.5	184.99	1.26	179	16.82	1
GNG469	320	175	1.28	247.5	236.64	0.94	145	42.32	3
RVG202	320	139	1.01	229.5	210.9	1.18	181	15.68	2
HC1	256	107	0.78	181.5	165.51	1.21	149	38.72	1
RSG888	345	198	1.44	271.5	261.36	0.89	147	40.5	3
DCP92-3	198	115	0.84	156.5	150.9	0.87	83	118.58	1
ICC1205(Ch)	360	181	1.32	270.5	255.26	1.04	179	16.82	3
RAU52	350	165	1.2	257.5	240.31	1.1	185	13.52	3
GG2	315	178	1.3	246.5	236.79	0.91	137	50	3
ANNEGIRI	260	159	1.16	209.5	203.32	0.81	101	92.48	2
JG315	367	146	1.06	256.5	231.48	1.26	221	1.28	3
JG74	258	149	1.09	203.5	196.07	0.88	109	81.92	2
DIGVIJAY	298	155	1.13	226.5	214.92	1	143	44.18	2
PBG5	350	125	0.91	237.5	209.17	1.34	225	0.72	1
GL769	241	117	0.85	179	167.92	1.07	124	63.845	1
PUSA 209	311	158	1.15	234.5	221.67	1.03	153	35.28	2
C235	390	158	1.15	274	248.23	1.24	232	0.125	3
PBG1	165	155	1.13	160	159.92	0.13	10	257.645	4
RSG931	305	149	1.09	227	213.18	1.07	156	32.805	2
ICC4958(Ch)	370	159	1.16	264.5	242.55	1.19	211	3.38	3

Contd.

Table 1 (*Concluded*)

Genotype	Yp	Ys	YI	MP	GMP	SSI	TOL	SM	Group
ICC07110	200	190	1.38	195	194.94	0.1	10	257.645	4
ICC96030	324	121	0.88	222.5	198	1.31	203	5.78	1
IPC09-161	259	122	0.89	190.5	177.76	1.1	137	50	1
ICC8950	385	148	1.08	266.5	238.7	1.28	237	0	3
ICC92944(ch)	270	165	1.2	217.5	211.07	0.81	105	87.12	2
ICCV10	270	141	1.03	205.5	195.12	1	129	58.32	2
HARINGHANTS	145	129	0.94	137	136.77	0.23	16	244.205	4
ICC4567	210	133	0.97	171.5	167.12	0.76	77	128	1
PDE-2E	158	98	0.71	128	124.43	0.79	60	156.645	4
ICC96029	115	84	0.61	99.5	98.29	0.56	31	212.18	4
PDG85-1	140	89	0.65	114.5	111.62	0.76	51	172.98	4
JG 2003-109	215	98	0.71	156.5	145.16	1.13	117	72	1
ICC7117	258	148	1.08	203	195.41	0.89	110	80.645	2
PDG 84-10	210	101	0.74	155.5	145.64	1.08	109	81.92	1
PUSA408	219	158	1.15	188.5	186.02	0.58	61	154.88	2
JG99-115	270	167	1.22	218.5	212.34	0.8	103	89.78	2
PUSA391	258	105	0.77	181.5	164.59	1.24	153	35.28	1
ICCV07118	208.1	173	1.26	190.55	189.74	0.35	35.1	203.8181	4
JG2002-87	305	105	0.77	205	178.96	1.37	200	6.845	1
JG2001-115	270	101	0.74	185.5	165.14	1.3	169	23.12	1
PUSA512	300	110	0.8	205	181.66	1.32	190	11.045	1
ICC37	185	169	1.23	177	176.82	0.18	16	244.205	4
JG01-14	330	122	0.89	226	200.65	1.31	208	4.205	1
ICC1356	180	167	1.22	173.5	173.38	0.15	13	250.88	4
IPC10-48	205	114	0.83	159.5	152.87	0.93	91	106.58	1
BARWAN	214	82	0.6	148	132.47	1.29	132	55.125	1
ICC15196	195	119	0.87	157	152.33	0.81	76	129.605	1
ICC81248	105	79	0.58	92	91.08	0.52	26	222.605	4
ICC14245	75	69	0.5	72	71.94	0.17	6	266.805	4
KPG59	369	168	1.22	268.5	248.98	1.14	201	6.48	3
RAJAS	385	187	1.36	286	268.32	1.07	198	7.605	3
ICC 10685	230	42	0.31	136	98.29	1.7	188	12.005	1
ICC1882	322	122	0.89	222	198.2	1.29	200	6.845	1
PUSA 240	286	234	1.71	260	258.7	0.38	52	171.125	3
VIJAY	315	205.4	1.5	260.2	254.36	0.73	109.6	81.1538	3
IPC06-11	350	225	1.64	287.5	280.62	0.74	125	62.72	3

Vallejo and Kelly 1998).Thus genotypes exhibiting higher MP, GMP and YI could be efficiently used in selecting superior genotypes under HS. While, emphasizing SSI index as selection parameter for heat tolerance genotypes showing SSI<1 were considered as higher heat tolerance (Poarch 2006). The result indicated that the genotypes RVG203 (0.78), JG130 (0.78), JAKI 9218 (0.6), ICCV 07118 (0.35), ICC 1356 (0.15) showed lower SSI value than the check ICC 92944 (0.81) (see Table1). Similarly this selection index was employed for selecting both heat and drought tolerance in common bean (Porch 2006, Ramirez-Vallejo and Kelly 1998) and drought tolerant genotypes in chickpea (Jha *et al.* 2016, Sabaghnia and Janmohammadi, 2014). Additionally, selection of superior genotypes based on lower value of SSI and TOL under drought tolerance was discussed in chickpea (Yucel and Mart 2014).

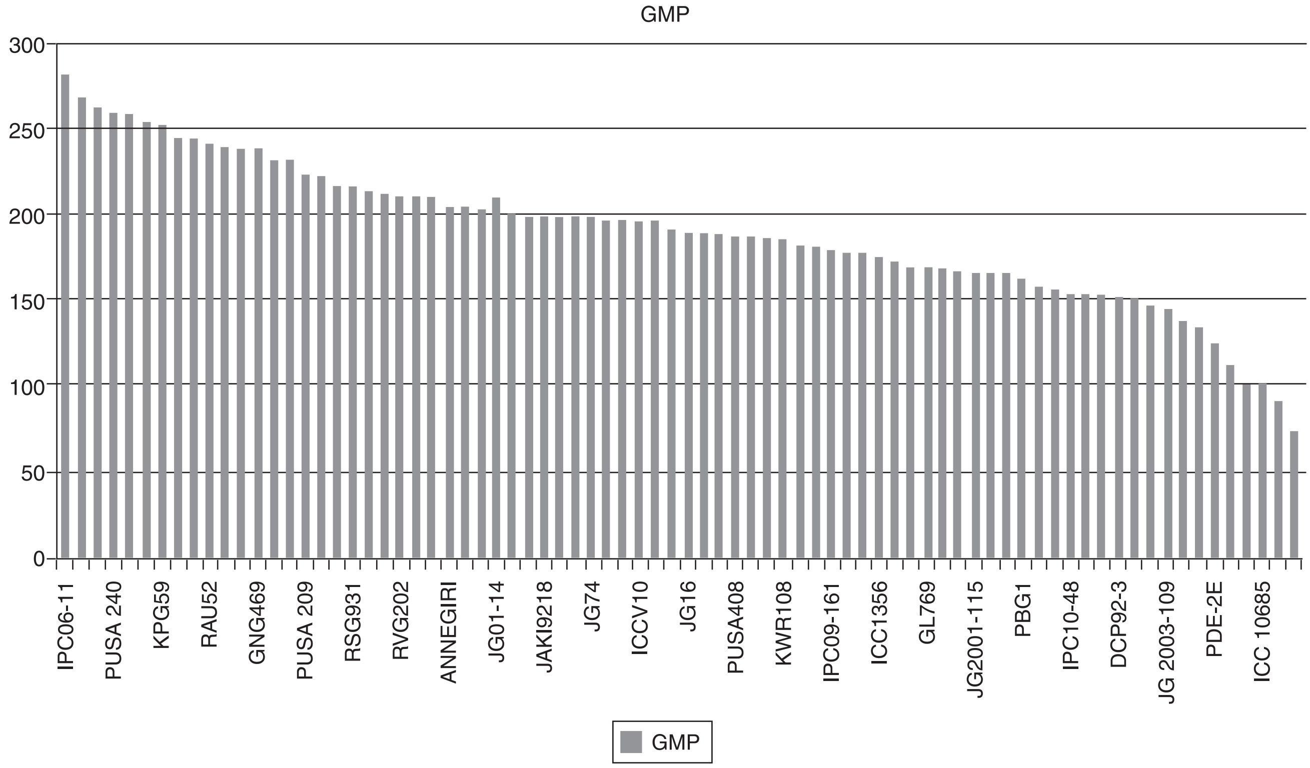

Fig 2 Variability of GMP of different chickpea genotypes as a function of non-stress and HS condition.

Correlation among the selected indices

In order to determine the desirable selection indices for HS tolerance, genotypic correlation coefficient between Yp and Ys and among the other heat tolerance indices were estimated. High and significant positive correlation of grain yield (Yp) under normal condition with all other indices viz., Ys, MP, YI, GMP, SSI and TOL were recorded except SM exhibited high and significant negative correlation with Yp. This result was in accordance with result obtained by Sabaghnia and Janmohammadi (2014) in chickpea under drought stress. Likewise, grain yield under HS condition (Ys) showed positive and high significant correlation with MP and GMP, whereas highly significant negative correlation of Ys with SSI was recorded. This result was in agreement with the result obtained in wheat under drought stress where Ys showed positive and significant association with GMP and MP (Anwar *et al.* 2011). Importantly, YI indicated significant and high positive correlation with MP and GMP, but it showed negative correlation with SSI. Similarly, Anwar *et al.* (2011) recorded positive and significant correlation of

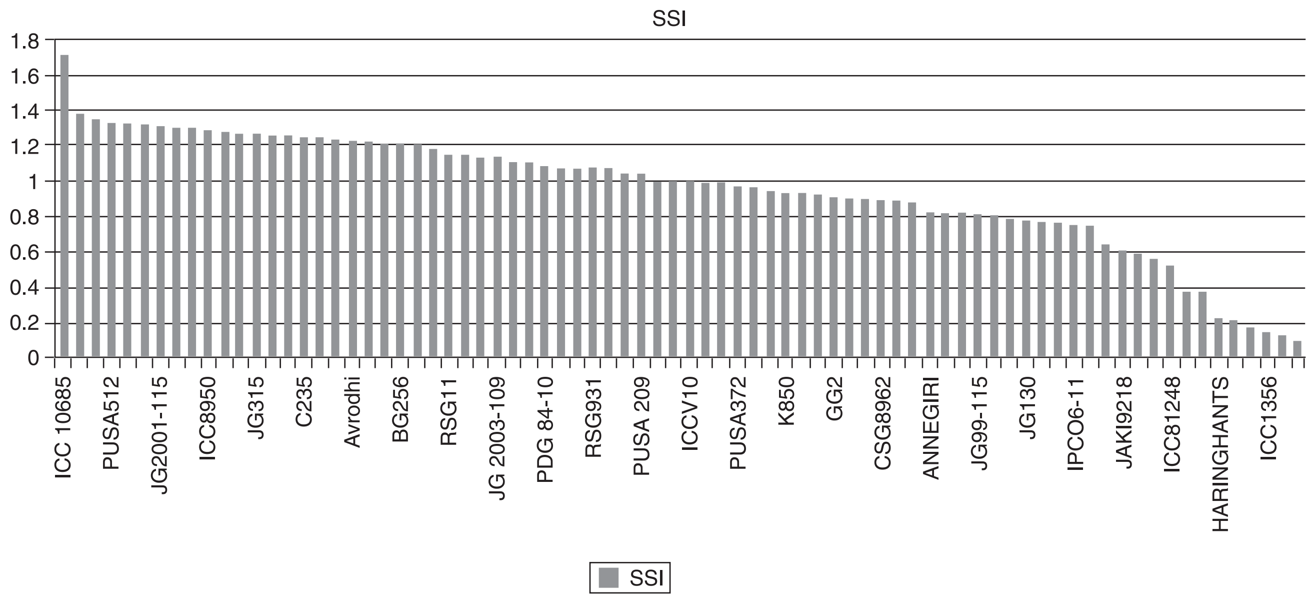

Fig 3 Variability of SSI of different chickpea genotypes as a function of non-stress and HS conditions.

YI with MP and GMP, respectively in wheat under water stress condition. Considering MP, it had high and positive correlation with GMP, SSI and TOL, except it had significant negative correlation with SM. Similarly, GMP showed high and positive correlation with SSI and TOL, but it indicated negative association with SM. Both SSI and TOL showed high significant negative association with SM, whereas SSI and TOL exhibited high positive correlation. This results remained consistent with the results obtained by Anwar *et al.* (2011) in wheat under drought stress.

Principal component analysis

The relationship among the genotypes and heat tolerance indices, are graphically depicted by PCA analysis. The PCA reduced all the indices into two components. The first component explained 61.9% variation with Yp, GMP, MP and Ys (Fig 4). While, the second component explained 37.1% variation with Yp, TOL and SSI indices. These results were in agreement with the results recorded by Jha *et al.* (2016) in chickpea under moisture stress condition.

Three dimensional plots analysis

To exploit the advantage of MP, GMP and YI indices for selecting genotypes performing well under HS and under normal condition three dimensional plots was depicted based on Ys, Yp and MP indices. All the 78 genotypes were categorized into four major groups. The genotypes, viz. GL769, PDG 3, PDG4, PBG5 belonging to first group showed poor yield under HS condition but showed higher yield under non stress condition. While the genotypes, viz. JAKI 9218, RVG 202, RVG 203 existing in group 4 showed higher yield under the both stress and non stress condition.

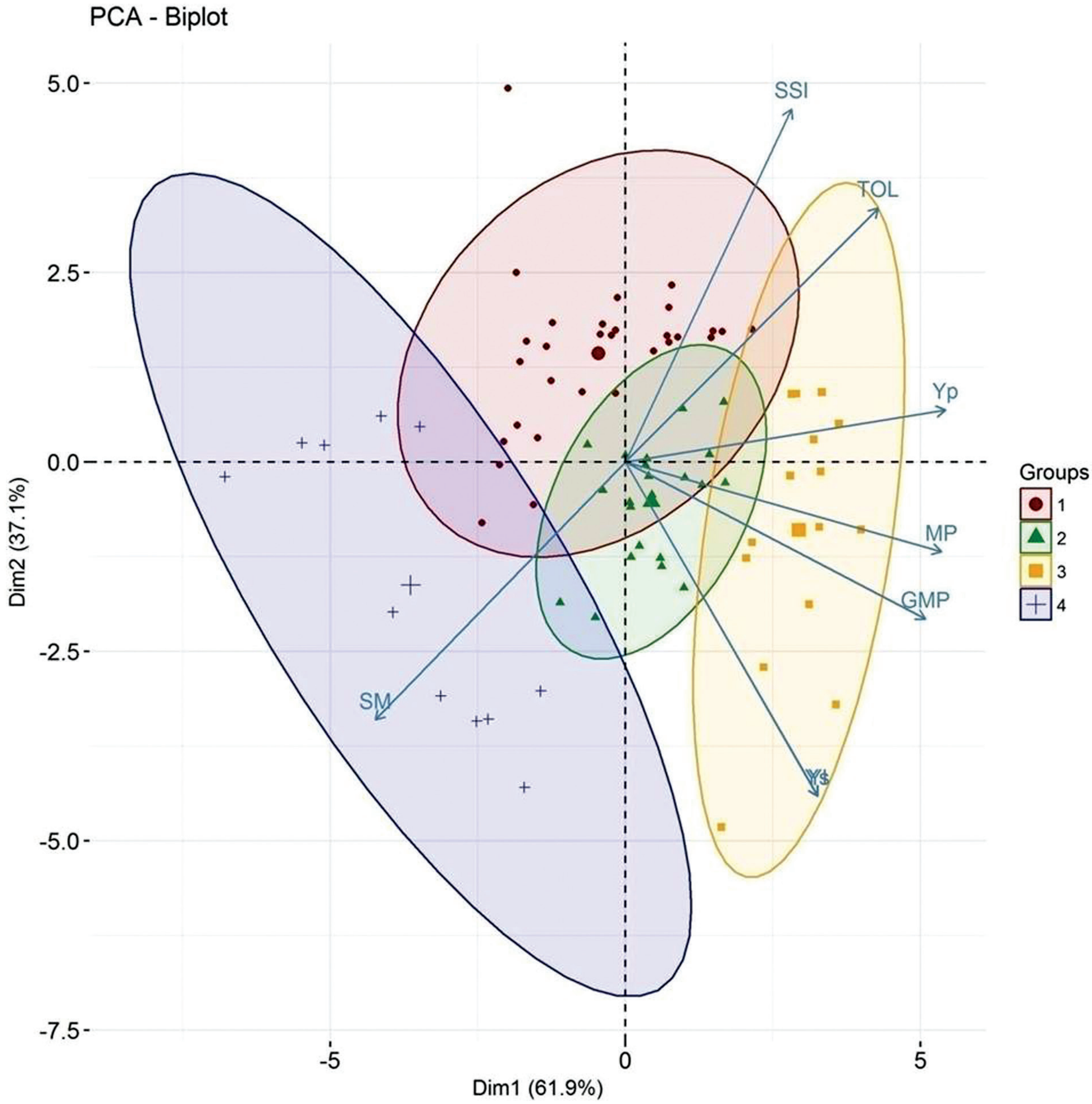

Fig 4 Biplot of 78 chickpea genotypes and 6 heat tolerance indices based on PC1 and PC2.

Considering second group the genotypes, viz. PDE-2E, ICC 96029, PDG 85-1 showed poor yield under both condition. The genotypes existing in group 3, viz. Rajas, Pusa 240, IPC 06-11 exhibited higher yield under both conditions. These results were in close agreement with the results obtained under drought stress in chickpea (Pouresmael *et al.* 2009, Jha *et al.* 2016).

Cluster analysis

Given the cluster analysis of genotypes based on Yp and Ys and other HS indices, four distinct clusters were generated. The first group contained 30 genotypes. Most of the genotypes, viz. DCP 92-3, GL 769, PDG 3, PDG 4, ICC 96030, ICC 10685 (Table 1) remaining in this group showed lower rank in context of various HS selection indices, viz. MP, GMP, YI, SSI discussed above. Thus these genotypes may be sensitive to HS. A total of 11 genotypes remained in second group. The genotypes, viz. ICC 07110, ICCV 07118, and ICC1356 existing in group 2 exhibited higher yields under both condition. Importantly 15 genotypes existed in third group. The genotypes such as ICC 8950, Vijay, Pusa 240, Rajas showed yield superiority to the check ICC 4958 genotype under the both conditions. Likewise, RSG 931, Pusa 209, RVG 203, JAKI 9218, and JG 99-115 genotypes belonging to group 4 showed higher yield than the heat tolerant ICC 92944 check and showed higher ranking based on various HS selection indices under the both conditions. Similarly, eight distinct clusters were suggested by Jha *et al.* (2015) based on various morpho-physiological traits recorded under HS in 62 chickpea genotypes. Moreover, considering various drought tolerance indices cluster analysis was performed to select superior drought tolerance genotypes in chickpea (Jha *et al.* 2016). Thus, the genotypes belonging to distant group could be exploited in crossing programme for developing HS tolerance genotype in chickpea.

Considering increasing incidences of yield loss in chickpea due to HS, the selection indices, viz. MP, GMP, YI and SSI can be efficiently employed in breeding programme for screening suitable genotypes to sustain chickpea yield under HS. The outcome of these important selection indices enabled in identifying RVG 203, RSG 888, JG130, JAKI 9218, ICCV 07118, ICC 1356, and IPC 06-11 genotypes as heat tolerant. Thus, these genotypes could be potentially introduced as donor parents into breeding programme for developing heat tolerance chickpea genotype.

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REFERENCES

Anwar J, Subhani G M, Hussain M, Ahmad J, Hussain M and Munir M. 2011. Drought tolerance indices and their correlation with yield in exotic wheat genotypes. *Pakistan Journal of Botany* **43**(3): 1527–30.

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

Devasirvatham V, Gaur P, Mallikarjuna N, Raju T N, Trethowan R M and Tan D K Y. 2013. Reproductive biology of chickpea response to heat stress in the field is associated with the performance in controlled environments. *Field Crops Research* **142:** 9–19.

Devasirvatham V, Gaur P, Mallikarjuna N, Raju T N, Trethowan R M and Tan D K Y. 2012. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Functional Plant Biology* **39**(12): 1009–18.

FAOSTAT. 2013. FAOSTAT database. Available at http://faostat3.fao.org/faostatgateway/to/download/Q/QC/E Verified 02 September 2014.

FAOSTAT. 2014. FAO Statistics Division. Available at: http://faostat3.fao.org/compare/E (accessed 27.02.16.).

Fischer R A and Maurer R. 1978. Drought resistance in spring wheat cultivars, I. Grain yield response. *Australian Journal of Agriculture Research* **29:** 897−912.

Gavuzzi P, Rizz F, Palumbo M, Campaline R G, Ricciardi G L and Borghi B. 1997. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journal of Plant Science* **77:** 523−31.

Graham P H and Vance C P. 2003. Legumes: Importance and constraints to greater use. *Plant Physiology* **131:** 872–7.

Jha U C, Bohra A and Singh N P. 2014a. Heat stress in crop plants: its nature, impacts and integrated breeding strategies to improve heat tolerance. *Plant Breeding* **133**(6): 679–70.

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

Jha U C and Shil S. 2015a. Association analysis of yield contributing traits of chickpea genotypes under high temperature condition. *Trends in Bioscience* **8:** 2335–41.

Jha U C, Basu P S and Singh D K. 2015b. Genetic variation and diversity analysis of chickpea genotypes based on quantitative traits under high temperature stress. *International Journal of Bio-resource Stress Management* **6:** 700–6.

Jha U C, Basu P and Shil S. 2016. Evaluation of drought tolerance selection indices in chickpea genotypes. *International Journal of Bio-resource Stress Management* **7**(6): 1244–8.

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 Breeding* **136**(4): 437–59.

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 on some winter crops in northwest India. *Current Science* **94:** 82–8.

Khan I and Dhurve O P. 2016. Drought response indices for identification of drought tolerant genotypes in rainfed upland (*Oryza sativa* L.). *International Journal of Science, Environment and Technology* **5**(1): 73–83.

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 Genetic Resources* **9**(1): 59–69.

Lin C S and Binns M R. 1988. A superiority measure of cultivar performance for Cultivar × Location data. *Canadian Journal of Plant Science* **68:** 193–8.

Lobell D B and Field C B. 2007. Global scale climate-crop yield relationships and the impacts of recent warming. *Environmental Research Letter* **2**: 014002.

Poarch T G. 2006. Application of stress indices for heat tolerance screening of common bean. *Journal of Agronomy and Crop Science* **192**: 390–4.

Pouresmael M, Akbari M, Vaezi S H and Shahmoradi S H. 2009. Effects of drought stress gradient on agronomic traits in Kabuli chickpea core collection. *Iranian Journal of Crop Science* **11:** 307–24.

Ramirez Vallejo P and Kelly J D. 1998. Traits related to drought resistance in common bean. *Euphytica* **99**: 127–36.

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

Rosielle A A and Hamblin J. 1981. Theoretical aspects of selection for yield in stress and non-stress environment. *Crop Science* **21:** 943−6.

Ryan J G. 1997. A global perspective on pigeonpea and chickpea sustainable production systems: present status and future potential. (*In*) Recent Advantages in Pulses Research, pp 1-31. Asthana A N, and Ali M (Eds). Indian Society of Pulses Research and Development, Indian Institute of Pulses Research, Kanpur, India, pp 1–31.

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

Yucel D and Mart D. 2014. Drought tolerance in chickpea (*Cicer arietinum* L.) genotypes. *Turkish Journal of Agricultural and Natural Sciences* **1:** 1299–1303.