Evaluation of selection indices for heat tolerance and their correlation with yield in some chickpea (*Cicer Arietinum* L.) genotypes of sudan

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Abstract

The major a biotic stresses affecting chickpea production are high and low temperature, drought and salinity. Heat stress is a major a biotic stress factor, constraining chickpea production worldwide. This study was conducted to identifying chickpea genotypes combining heat tolerance and high yield potential and to study correlation among the heat tolerance indices. The genotypes were tested under different field-growing conditions, normal sown (non – heat stress) and late sown (heat stress) at two locations, Merowe and Gezira during winter season 2018/2019. The trials were laid out in alpha lattice design with three replications. Eight heat tolerance indices, which were most frequently used in plant breeding including, geometric mean productivity (GMP), yield index (YI), mean productivity (MP), stress susceptibility index (SSI), stress tolerance index (STI), tolerance index (TOL), sensitivity heat index (SHI) and relative heat index (RHI) were calculated based on seed yield under heat stress (Ys) and non – heat stress (Yp) conditions. Under both environments, the results from combined analysis of variance showed that there were highly significant differences among the gen-otypes for all traits studies. There were highly significant differences observed among the tested chickpea genotypes response to heat stress. Seed yield in stress (Ys) condition was positive and highly significant correlated with geometric mean productivity, yield index, stress tolerance index and relative heat index. The Ys was negative and highly significant correlated with stress susceptibility index and sensitivity heat index. Seed yield in non-stress (Yp) condition was positive and significant correlated with geometric mean productivity, yield index, stress tolerance index and tolerance index. The results of this research showed that the six indices, GMP, YI, SSI, STI, SHI and RHI can be used as optimal indicators for screening heat tolerant chickpea genotypes. Nine genotypes including four released improved varieties (Shiekh Mohamed, Wad Hamid, Salwa and Hwata) and five

genotypes (no. 11, 4, 26, 30 and 34) are most stable chickpea genotypes for heat tolerance and can be further used in breeding program. These genotypes can be used in the chickpea national breeding program to develop varieties with improved heat tolerance in Sudan. Genotype no. 11 (FLIP 08-59 C) was release by Sudan national variety release committee for commercial production under the name Elbarkal in September 2022 to will be grown in Gezira, River Nile and Northern States of Sudan.

Introduction

Among the food legumes, chickpea occupies second position after beans. It is cultivated in more than fifty countries worldwide [1,2]. Chickpea grains are nutritious and a leading source of proteins, carbohydrates, vitamins and minerals for the masses in many developing and non-developing nations. World's major chickpea production comes from India, Australia, Pakistan, Turkey, Burma, Ethiopia and Iran where the crop is largely grown on arid and semi arid tropics, dependent on rainfall as a source for soil moisture [1].

In Sudan, chickpea is the third most economically important food legume crop after faba bean and cowpea, as a cash crop that generates income for farmers and rural communities, and as a significant source of protein for Sudanese people [3]. It is traditionally grown as a winter crop in River Nile State, northern Sudan. However, chickpea production has recently expanded to the central clay plain of central Sudan. Nevertheless, a biotic stresses remain one of the leading constraints to the global chickpea productivity, causing serious yield loss [4].

Chickpea reproductive stages (flowering and podding) are vulnerable to external environmental changes and heat stress [5]. Frequent decreases in the yields of chickpea seed were observed when plants were exposed to high (> 35°C) temperatures at flowering and pod development stages [6]. Most importantly, increasing evidences of heat stress (HS) is receiving serious attention and, is going to be an emerging threat to the cool season grown global food crops including chickpea [7]. A 1 C^0 increase in seasonal temperature decreased chickpea yield by 53 kg ha^{-1} [8].

Several indices based on the yield under non-heat stress (Yp) and heat stress (Ys) have been introduced for the selection of heat tolerant genotypes. Among these, the indices employed in various stress conditions are stress tolerance (TOL) and mean productivity (MP) introduced by some re-searchers [9]. Stress susceptibility index (SSI) was also produced in 1978 [10]. Moreover, stress tolerance index (STI) and geometric mean productivity (GMP) produced in 1992[11], while Harmonic mean of yield (HM) was released in 2009 [12]. Furthermore, yield index (YI) was introduced in 1997 [13], and the yield reduction ratio (YRR) in 1998 [14].

To date, limited genetic resources for heat stress tolerance in chickpea have been reported [15,]. In order to screen heat tolerant crop genotypes, several physiological and plant breeding based parameters are available [6,17]. Equally, yield based indices are also essential for comparing crop performance under non stress and stress condition and thus enable in selecting superior genotype [8].

Thus, achieving optimum grain yield under heat stress remains prime criteria to chickpea breeders. Implication of various indices helps in measuring yield loss and screening heat stress tolerant genotype under stress condition [19]. However, heat tolerant varieties/cultivars are needed for improving chickpea yields in warm season environments and late sowing conditions especially in central Sudan (Gezira State), to expand its cultivation to new areas and improving its resilience to the impacts of climate change. The genetic variability presents in the base population for desired characters play an important role in development of improve chickpea genotypes. Less information is available on chickpea genotypes tolerance to heat grown under Sudan conditions. Keeping in view the above research findings, the present study was carried out to investigate different heat tolerance indices as well as their correlation and indentifying the potential chickpea genotypes for heat stress and non-heat stress conditions.

Materials and methods

The study area of this research was conducted over one consecutive winter season 2018/2019 in two locations in the Agricultural Research Corporation (ARC) of Sudan. Namely the Gezira Research Station Farm (GRSF), located in central clay plain of Sudan within the latitude 14°24' N, and longitude 33°29' E and altitude 407 meters above sea level with soil characterized by cracking heavy clay (vertisols), very low water permeability, pH of 8.3, organic matter (0.4%), nitrogen (0.04% ppm), and phosphorus (ESP, 4 ppm) and (2) farmers field in the Northern state of Sudan, Merowe locality (latitude: 18° 27' 0" N, longitude: 31° 49' 59" E, elevation: 258 meters above sea level).

Forty three chickpea genotypes were selected from advanced materials of the national chickpea breeding program. In addition, five commercial chickpea cultivars which were released by the Agricultural Research Corporation of Sudan namely, Shiekh Mohamed, Merowe, Wad Hamid, Salwa and Hwata (Table 1).

Across all growing locations, the land was prepared by disc ploughing, disc- harrowing, leveling and ridging. In two locations the genotypes were evaluated in two environments i.e., normal sown (15 November) and late sown (5 December). The experiment was conducted in Alpha Lattice design with three replications under normal sown and late sown conditions. Each replicate consisted of twelve in-complete blocks and four plots in each block. Each genotype was planted in a separate plot which was consisted of one ridge /row of 4 meter length, with a plant-to-plant and row-to-row distance of 10 cm and 60 cm, respectively. The plots were separated by a distance of 60 cm. Irrigation was carried out at 12-14 days intervals to avoid any water stress. A starter dose of nitrogen in the form of urea urea was applied at a rate of 43 kg N/ha with the third irrigation. Weeds were kept to the minimum by hand removal during the first month after sowing. Seed yield was assessed from a net area of 2.4 m^2 (one row x 4 m long x 0.6m).

Data of the following parameters were collected

Phenological and growth parameters which include

(a) Days to 50% flowering: Days to 50% flower initiation was recorded as the number of days required from planting to the time when 50% of plants in plots produced at least one flower.

(b) Days to 90% physiological maturity: Days to 90% physiological maturity was recorded as the number of days required from planting to the time when 90% of plants showed a yellow color in each plot before senescence.

(c) Plant height: Plant height was recorded from ten randomly taken plants from one central row at physiological maturity from ground to the tip of the main stem and then the mean was recorded as height per plant (cm).

Yield component and yield

(a) Number of pods per plant: It was counted from the total number of seed bearing mature pods was counted separately from randomly selected five plants in each plot and averaged.

Table 1. Names, genetic background (pedigree) and origin of chickpea genotypes used in this study.

No.	Accession No.	Genetic background (pedigree)	Origin
1	FLIP 09 – 181 C	X06TH53/FLIP03-128CXFLIP01-25C	ICARDA
2	LIP 09 – 179 C	X06TH53/FLIP03-128CXFLIP01-25C	ICARDA
3	FLIP 09 – 184 C	X06TH53/FLIP03-128CXFLIP01-25C	ICARDA
4	FLIP09 – 155 C	X06TH71X05TH104XFLIP03-39C	ICARDA
5	FLIP09 – 438 C	S00794(60 KR)-44	ICARDA
6	FLIP09 – 261 C	X04TH32/X03TH-32XFLIP99-34	ICARDA
7	FLIP 07 – 236 C	X03TH138/FLIP98-130CXFLIP99-34C	ICARDA
8	FLIP 09 – 259 C	X04TH32/X03TH-32XFLIP99-34C	ICARDA
9	FLIP08 – 86 C	X03TH144/FLIP97-116CXFLIP97-32C	ICARDA
10	FLIP09 – 6 C	X05TH22/(FLIP99-46CXFLIP97-91C)XFLIP02-43C	ICARDA
11	FLIP 08-59 C	X02TH3/FLIP 98-28C X FLIP-97-102C	ICARDA
12	FLIP 09-182 C	X06TH53/FLIP03-128C X FLIP01-25C	ICARDA
13	FLIP 09-187 C	X06TH53/FLIP03-128CXFLIP01-25C	ICARDA
14	FLIP09 – 240 C	F2X01TH186 (45KR)-3	ICARDA
15	22330	70755	ICARDA
16	22304	70381	ICARDA
17	22317	70309	ICARDA
18	22233	9440	ICARDA
19	22278	70334	ICARDA
20	22267	70304	ICARDA

21	22232	9439	ICARDA
22	22223	9425	ICARDA
23	22235	9442	ICARDA
24	22366	74021	ICARDA
25	22293	70357	ICARDA
26	22380	1E+05	ICARDA
27	22362	73386	ICARDA
28	22254	70273	ICARDA
29	22335	70764	ICARDA
30	22204	6057	ICARDA
31	22272	70312	ICARDA
32	222389	1E+05	ICARDA
33	222303	70379	ICARDA
34	222242	69620	ICARDA
35	22373	75360	ICARDA
36	22206	6109	ICARDA
37	22384	70780	ICARDA
38	22341	70773	ICARDA
39	22302	70377	ICARDA
40	22260	70286	ICARDA
41	22266	70299	ICARDA
42	22392	1E+05	ICARDA
43	22261	70290	ICARDA
44	Shiekh Mohamed	X99TH62/(FLIP932CxFLIP 94-115C)	Released commercial cultivar
45	Merowe	X99TH62/(FLIP932CxFLIP 94-115C)	Released commercial cultivar
46	Wad Hamid	(India-ICRISAT Selection)	Released commercial cultivar
47	Salwa	(X87TH 186/ ICCI 4198)//FLIP 82-150C)	Released commercial cultivar
48	Hwata	(ICCV2/Surutato 77)//ICC 7344)	Released commercial cultivar

(b) Number of seeds per plant: It was counted from the sample after threshing, as counted from each five randomly taken plants per middle of row and then expressed as an average of 5 plants.

(c) Number of seeds per pod: This was calculated by dividing the total number of seeds per plant (of the sample) by the total number of pods per plant.

(d) Hundred-seed weight (g): It was calculated by 100 seed samples were randomly selected from each plot and seeds weighted.

(e) Seed yield per plant (g): It was calculated as the total seed produced from five randomly selected plants after threshing and cleaning was weighted in gram with the help of electronic top pan balance and averaged out for seed yield per plant (g).

Harvest index (HI): It was calculated as the ratio of economic yield divided to the total of biological yield expressed in percentage. HI (%) = (Seed yield / Biological yield) x 100

(f) Biomass (t ha^{-1}): Biological yield is the total yield of crop including economic yield and the straw yield. The biological yield was recorded after harvesting using electronic balance (in g or kg net plot) and converted into (t ha^{-1}).

(g) Seed yield (t ha^{-1}): When signs of maturity were clear on the plant (complete yellowing of leaves), four meter length in each plot was harvested for yield, weighed and then seed yield per plot was converted to seed yield in ((t ha^{-1}) adjusted at 10% moisture content.

Estimation of heat indices

Eight heat tolerance indices namely, geometric mean productivity (GMP), yield index (YI), mean productivity (MP), stress susceptibility index (SSI), stress tolerance index (STI), tolerance index (TOL), sensitivity heat index (SHI) and relative heat index (RHI) were calculated by the given formulae:-

Geometric mean productivity (GMP) = $(Ypi \times Ysi)^{0.5}$. The genotypes with high GMP values consider being tolerant to heat stress [11].

Yield index (YI) = (Ysi/ Ys) Genotypes with high values of this index indicate to be suitable for heat stress condition [13].

Mean productivity (MP) = (Ypi+Ysi) / 2. The genotypes with high values of this index found to be more desirable [20].

Stress susceptibility index (SSI) = (1-(Ysi/Ypi))/SI. The genotypes with least SSI values have tolerant to heat stress [10].

Stress tolerance index (STI) = (Ypi/Yp) (Ysi/Ys) (Ys/Yp) The genotypes with high STI values have tolerant to heat stress [11].

Tolerance index (TOL) = (Ypi-Ysi). The genotypes with minimum TOL values have tolerant to heat stress [9].

Sensitivity heat index (SHI) = (Ypi - Ysi) / Ypi. The genotypes with least SHI values have tolerant to heat stress [21].

Relative heat index (RHI) = (Ysi / Ypi) / (Ys/Yp). The genotypes with maximum RHI values have tolerant to heat stress [22]. Reduction percentage was calculated as follows:

% Reduction = (Ypi-Ysi)/Ypi x 100 [23].

In the above formulas Ysi, Ypi, Ys and Yp represent yield under heat stress, yield under non-heat stress for each genotype, yield mean in heat stress and non-heat stress conditions for all genotypes, respectively.

The collected data were subjected to combine analysis of variance using the GenStat 12th edition statistical analysis package for windows (2009) to test the level of significance among the genotypes for different traits under non – heat stress and heat stress conditions. The correlation analysis was worked out according to the method described by [24].

Discussion

The results of the analysis of variance for different traits under non-heat stress and heat stress conditions are presented in Table 2. There were highly significant differences among the genotypes for all the various Agro-morphological traits were recorded under both normal sown (non-heat stress) and late sown (heat stress) conditions, indicating the presence of variability that can be exploited through selection. This result was inconformity with the results reported by many authors, [25]. Similarly, previous studies on chickpea landraces also reported by [26,27]. The interaction between genotype (G) x location (L) were not significantly for some traits under heat stress and non-heat stress field conditions.

Different heat tolerance indices were calculated on the basis of seed yield of the chickpea genotypes under normal sowing date (non-heat stress) (Ypi) and late sowing date (heat stress) (Ysi) conditions are presented in (Table 3). The highest seed yield (3.93 t ha^{-1}) under non-heat stress (Ypi) condition was obtained by two genotypes no. 1 and 40, while the lowest (1.84 t ha^{-1}) was produced by genotype no. 41. On the other hand, under heat stress condition (Ysi), the highest seed yield (2.52 t ha^{-1}) was recorded for genotype no. 11 and the lowest (0.83 t ha^{-1}) for the genotype no. 28 (Table 3).

Comparison of genotypes based on reduction of yield and yield related traits by growing them under non-heat stress and heat stress environments could be an important parameter for selection of tolerant genotype under drought, heat and other a biotic stresses in crop plants [28,29]. In the present study, Reduction in yield as affected by heat varied among chickpea genotypes and ranged between 8.9% and 66.7%.

Similarly, several kinds of stress indices based on seed yield are available that help in comparing crop performance under non-stress and stress condition and thus, enable selection of superior genotypes [18]. Likewise, heat tolerance indices viz, geometric mean productivity (GMP), yield index (YI), mean productivity (MP), stress susceptibility index (SSI), stress tolerance index (STI) and tolerance index (TOL) could be employed for selecting superior genotypes relying on yield performance under heat stress in field condition.

The genotype no. 11 and the check Wad Hamid (no. 46) exhibited excellent seed yield in heat stress (2.52 and 2.35 t ha^{-1} as well as in non - heat stress condition (3.29 and 2.58 t ha^{-1} (Table 3). Further, these two genotypes have the least stress susceptibility index (0.48 and 0.18) and minimum reduction in seed yield (23.3% and 8.9%) respectively, due to heat stress. It is reported that heat resistant genotype had the highest heat tolerance efficiency, minimum heat susceptible index and minimum reduction in seed yield due to heat stress [30].

Considering YI as an important selection index for heat tolerance, genotypes no. 11(1.65), 47 (1.57), 48 (1.49), 4 (1.39), 44 (1.36), 43 (1.30), 34 (1.27), 30 (1.25) and 26 (1.22), showed higher YI value than the check Merowe (1.15) (Table 3). While, considering MP as an important selection index for

Table 2. Mean squares for locations, genotypes and their interaction of some traits of forty eight chickpea genotypes, combined over two locations (Merowe and Gezira) under non-heat stress and heat stress field conditions.

Traits	Location (L)		Genotype (G)		L x G	
	Non-heat stress	Heat stress	Non-heat stress	Heat stress	Non-heat stress	Heat stress
DF	1200.50***	2.00$^{n.s}$	364.92***	295.72***	36.02***	55.48$^{n.s}$
DM	20334.72***	11312.59***	156.04***	80.88***	126.49***	64.37***
PH	4985.01***	8109.01***	142.92***	120.37***	33.17$^{n.s}$	61.11***
NPP	161420.9***	82872.0***	2254.4***	1166.2***	1812.4***	1111.3***
NSPL	303031.1***	147451.7***	3962.7***	2006.9***	2412.2***	1678.2***
NSP	1.87857***	1.77818***	0.12627***	0.12043***	0.02964$^{n.s}$	0.03048$^{n.s}$
100-SW	703.12***	1984.50***	246.21***	268.15***	27.20**	19.49*
SYP	32340.60***	24708.65***	223.21***	198.02***	179.08***	143.18***
HI (%)	5352.68***	1880.38***	122.50***	91.64***	125.81***	97.10***
BIO	669911156***	826400961***	10556848***	7051932***	9667824***	5703943***
SY	1439480$^{n.s}$	61633678***	1929551**	1029497***	1115749$^{n.s}$	551317***

DF: Number of days to 50% flowering, DM: Number of days to 90% maturity, PH: Plant height (cm), NPP: Number of pods per plant, NSPL: Number of seeds per plant, NSP: Number of seeds per pod, 100-SW: Hundred seed weight, SYP: Seed yield per plant (g), HI (%): Harvest index, BIO: Biomass (t ha-1) and SY: Seed yield (t ha-1).

*, ** and *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

n.s = non - significant difference at 0.05 probability level.

Table 3. Mean comparison of heat tolerance indices and seed yield (t ha-1) of tested 48 chickpea genotypes under both non – heat stress (Ypi) and heat stress (Ysi) conditions.

No.	Ypi	Ysi	% reduction in yield	GMP	YI	MP	SSI	STI	TOL	SHI	RHI
1	3.93	1.52	61.4	2442	0.99	2725	1.26	0.64	2416	0.61	0.75
2	2.61	1.36	47.9	1880	0.89	1981	0.98	2.37	1251	0.47	1.01
3	3.78	1.32	65.0	2233	0.86	2549	1.33	2.65	2457	0.65	0.68
4	3.45	2.12	38.6	2704	1.39	2786	0.79	3.07	1336	0.38	1.19
5	3.21	1.75	45.3	2370	1.15	2479	0.93	2.74	1455	0.45	1.06
6	3.64	1.30	64.2	2175	0.85	2470	1.32	2.59	2338	0.64	0.69
7	2.74	1.37	49.8	1941	0.90	2058	1.02	2.34	1368	0.50	0.97
8	2.72	1.05	61.4	1690	0.68	1886	1.26	2.12	1674	0.61	0.75
9	2.82	1.05	62.6	1721	0.69	1935	1.28	2.15	1766	0.62	0.72
10	3.45	1.42	58.7	2214	0.93	2436	1.20	2.61	2028	0.58	0.80
11	3.29	2.52	23.3	2881	1.65	2907	0.48	3.27	770	0.23	1.49
12	2.58	1.74	32.4	2119	1.14	2161	0.66	2.52	838	0.32	1.31
13	3.20	1.77	44.7	2381	1.16	2487	0.91	2.75	1434	0.44	1.07
14	3.51	1.61	54.1	2376	1.05	2559	1.11	2.75	1899	0.54	0.89
15	2.83	1.29	54.5	1909	0.84	2059	1.12	2.31	1545	0.54	0.88
16	2.84	1.63	42.5	2154	1.07	22238	0.87	2.54	1210	0.42	1.11
17	2.20	1.09	50.4	1550	0.71	1647	1.03	1.97	1112,	0.50	0.96
18	3.00	1.50	49.9	2121	0.98	2250	1.02	2.51	1498	0.50	0.97
19	3.45	1.70	50.8	2418	1.11	2573	1.04	2.79	1756	0.50	0.96
20	2.18	1.12	48.5	1566	0.73	1653	0.99	1.98	1059	0.48	1.00
21	3.16	1.42	54.8	2120	0.93	2290	1.12	2.51	1733	0.55	0.87
22	2.55	1.47	42.1	1937	0.96	2010	0.86	2.34	1075	0.42	1.12
23	3.04	1.12	63.2	1845	0.73	2081	1.29	2.27	1925	0.63	0.71
24	2.88	1.14	60.3	1816	0.75	2014	1.24	2.23	1740	0.60	0.77
25	2.90	1.44	50.3	2042	0.94	2168	1.03	2.43	1459	0.50	0.96
26	2.73	1.86	31.9	2250	1.22	2292	0.65	2.65	872	0.31	1.32
27	3.40	1.69	50.2	2399	1.11	2546	1.05	2.77	1707	0.50	0.96
28	2.09	0.83	60.0	1318	0.54	1459	1.23	1.76	1251	0.60	0.77
29	2.94	1.50	48.8	2100	0.98	2219	1.00	2.49	1435	0.48	0.99
30	3.14	1.91	39.1	2447	1.25	2524	0.80	2.82	2130	0.39	1.18
31	2.40	1.51	37.1	1900	0.99	1952	0.76	2.31	891	0.37	1.22
32	2.87	1.10	61.6	1773	0.72	1982	1.26	2.20	1768	0.61	0.74
33	1.86	0.98	47.2	1353	0.64	1423	0.97	1.78	880	0.47	1.02
34	3.22	1.94	39.5	2500	1.27	2581	0.81	2.87	1272	0.39	1.17
35	2.74	1.44	47.3	1986	0.94	2089	0.97	2.38	1295	0.47	1.02

No.	Ypi	Ysi	% reduction in yield	GMP	YI	MP	SSI	STI	TOL	SHI	RHI
36	2.20	1.61	26.7	1885	1.06	1908	0.55	2.31	589	0.26	1.42
37	2.03	0.89	56.2	1341	0.58	1458	1.15	1.78	1142	0.56	0.85
38	3.26	1.16	64.3	1945	0.76	2211	1.32	2.37	2100	0.64	0.69
39	3.59	1.56	56.6	2361	1.02	2571	1.16	2.74	2032	0.57	0.84
40	3.93	1.31	66.7	2264	0.85	2616	1.37	2.69	2620	0.66	0.64
41	1.84	0.93	49.3	1307	0.61	1384	1.01	1.74	907	0.49	0.98
42	1.91	1.07	44.0	1431	0.70	1492	0.90	1.86	844	0.43	1.09
43	3.58	1.99	44.4	2670	1.30	2787	0.91	3.03	1594	0.44	1.08
44	3.02	2.08	31.0	2509	1.36	2553	0.63	2.90	940	0.31	1.34
45	3.91	1.76	54.8	2624	1.15	2835	1.12	2.99	2144	0.54	0.87
46	2.58	2.35	8.9	2459	1.54	2462	0.18	2.92	232	0.08	1.77
47	3.51	2.40	31.4	2900	1.57	2953	0.64	3.27	1104	0.31	1.33
48	3.53	2.28	35.3	2834	1.49	2902	0.72	3.20	1247	0.35	1.25
Mean	2.96	1.52									

GMP = Geometric mean productivity, YI = Yield index, MP = Mean productivity, SSI = Stress susceptibility index, STI = Stress tolerance index, TOL = Tolerance index, SHI = Sensitivity heat index and RHI = Relative heat index.

Table 4. Correlation between heat tolerance indices with seed yield under normal sown (non-heat stress) and late sown (heat stress) conditions.

Traits	GMP	YI	MP	SSI	STI	TOL	SHI	RHI
YI	0.9042***							
MP	0.1587$^{n.s}$	0.1579$^{n.s}$						
SSI	-0.3857**	-0.7383***	-0.0967$^{n.s}$					
STI	0.7554***	0.7578***	0.1257$^{n.s}$	-0.4333**				
TOL	0.1839$^{n.s}$	-0.2390$^{n.s}$	-0.0173$^{n.s}$	0.7942***	-0.0283$^{n.s}$			
SHI	-0.3859**	-0.7380***	-0.0977$^{n.s}$	0.9996***	-0.4324**	0.7937***		
RHI	0.3870**	0.7391***	0.0944$^{n.s}$	-0.9998***	0.4322**	-0.7931***	-0.9997***	
Ypi	0.8046***	0.4770***	0.0995$^{n.s}$	0.2235$^{n.s}$	0.5032***	0.7118***	0.2224$^{n.s}$	-0.2219$^{n.s}$
Ysi	0.9058***	0.9999***	0.1563$^{n.s}$	-0.7357***	0.7577***	-0.2355$^{n.s}$	-0.7353***	0.7366***

GMP: Geometric mean productivity, (YI): Yield index, (MP): Mean productivity, (SSI): Stress susceptibility index, (STI) , Stress tolerance index, (TOL): Tolerance index, (SHI): Sensitivity heat index, (RHI): Relative heat index, Ypi: Mean seed yield of individual genotype in non – heat stress condition and Ysi: Mean seed yield of individual genotype in heat stress condition.

** and *** Significant at 0.01 and 0.001 probability levels, respectively.

n.s = non - significant difference at 0.05 probability level.

heat tolerance, eleven genotypes viz., 47 (2953), 11 (2907), 48 (2902), 45 (2835), 43 (2787), 4 (2786), 1 (2725), 40 (2616), 34 (2581), 39 (2571) and 30 (2524) showed higher MP value than the check Wad Hamid (2462). Importantly, considering GMP as an important selection index for heat tolerance, genotypes no. 47, 48, 11, 4, 45, 43, 44 and 34 showed higher value than the check Wad Hamid (no. 46) (Table 3). Importantly, YI index as an important selection parameter for drought tolerance in rice have been reported [31]. Similarly based on this parameter both drought and heat tolerant genotypes were identified in common bean [18].

Thus genotypes exhibiting higher MP, GMP and YI could be efficiently used in selecting superior genotypes under heat stress. While emphasizing SSI as another important selection parameter for heat tolerance, genotypes showing SSI<1 were considered as higher heat tolerance **[18]**. The result indicated that the genotypes no. 11 and 36 showed lower SSI value than the four checks Shiekh Mohamed, Merowe , Salwa and Hwata (Table 3). Similarly this selection index was employed for selecting drought tolerant genotypes in chickpea [32,33]. Additionally, selection of superior genotypes based on lower value of SSI and TOL under drought tolerance was discussed in chickpea [34]. According to stress tolerance index (STI), genotypes no. 11, 47, 48, 4 and 43 exhibited the most and 1, 41 and 28 the least relative tolerance, respectively [35].

Study [34] indicated that the genotypes with high STI usually have high difference in yield in two different conditions. They reported in general, similar ranks for the genotypes were observed by GMP and MP parameters as well as STI, which suggests that these three parameters are equal for screening heat tolerant genotypes. For sensitivity heat index (SHI) and relative heat index (RHI), the genotypes no. 11, 46, 4, 12, 26, 30, 31, 44, 47, 48 and 36 were the most relative tolerant genotypes. The genotypes no. 11. 4, 34, 26 and 30 plus the commercial cultivars, Wad Hamid (no. 46), Shiekh Mohamed (no.44), Salwa (no. 47) and Hwata (no.48) recorded least stress susceptibility index and minimum reduction in seed yield, maximum geometric mean productivity, highest yield index, maximum mean productivity, maximum stress tolerance index, minimum tolerance index, least sensitivity heat index and maximum relative heat index.

To determine the most desirable heat tolerant criteria, the correlation coefficients between Yp, Ys and other quantitative indices of heat tolerance were calculated (Table 4). In other words, correlation analysis between seed yield and heat tolerance indices can be a good criterion for screening the best cultivars and indices used. Seed yield in stress condition (Ys) was positively and significantly corrected with geometric mean productivity, yield index, stress tolerance index and relative heat index and negatively and highly significant correlated with stress susceptibility index and sensitivity heat index. This indicates that these six factors were more effective in identifying high-yielding cultivars when heat stress was present.

It was found that seed yield under heat stress condition (Ys) showed negative and highly significant correlation with SSI [36]. It is reported) that GMP and STI were significantly and positively correlated with stress seed yield [37]. On the other hand, Yield in non-heat stress condition (Yp) was positive and highly significant correlated with geometric mean productivity, yield index, stress tolerance index and tolerance index. A researcher [38] found the seed yield under non-heat stress (Yp) was positively and highly significantly correlated with GMP and STI. It is believed that the most appropriate index for selecting stress tolerant cultivars is an index which has partly high correlation with seed yield under stress and non-stress conditions. Seed yield in non-stress (Yp) condition was positive and non-significant correlated with stress susceptibility index [39]. This result was comparable to result obtained by Ehdaie and Shakiba 1996 [40] found in wheat that there was no correlation between stress susceptibility index and yield under optimum condition.

Considering MP, it had high and positive correlation with GMP, YI, STI, RHI and Yp but it had negative correlation with TOL and SHI. STI showed high and positive correlation with GMP, YI, RHI, Yp and Ys, but it indicated negative association with SSI and RHI. Both SSI and TOL showed high significant negative association with RHI, whereas SSI and TOL exhibited high positive correlation.

Conclusion and recommendations

Based on results of this study, it could be concluded that there was a wide range of genetic variability detected among the seed chickpea genotypes for heat tolerance. This variability can be exploited in the improvement for heat tolerance in this crop.

The environmental stress (heat stress) has been confirmed reduce seed yield of all chickpea genotypes.

However, GMP, YI, STI and RHI show highly significant and positive correlation with seed yield under stress only when stress is too severe. These four indices can be considered as suitable criteria for selecting heat tolerant and highly efficient genotypes in environments where heat is predominant. While the SHI and SSI showed negative and highly significant correlation with yields under heat stress condition. These two indices can be also used as the most suitable indicators for selecting heat tolerant chickpea genotypes.

In consideration to all indices, the cultivars, no. 44 (Shiekh Mohamed), 46 (Wad Hamid), 47 (Salwa) and 48 (Hwata) and genotypes, no. 11, 4, 30, 34 and 26 were found to be high yielding and hence they were defined as the most heat tolerant genotypes. These genotypes are intended for further evaluation for varietal approval to recommend for general cultivation on farmer fields in heat affected areas. While the genotypes no. 28, 41, 42, and 33 were the most sensitive for heat stress.

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