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Studies on Genetic Parameters for Various Agronomic Characters in Chickpea (*Cicer arietinum* L.) Genotypes Under Normal and Heat Stress Conditions in Northern Sudan

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Abstract

Chickpea (*Cicer arietinum* L.) is an important cool season food legumes with indeterminate growth habit. The productivity of the crop is constrained by several a biotic stresses, among which high temperature is one of the key determinants of crop. Two field experiments were conducted at Merowe farmers' field in Northern Sudan under non-heat stress and heat stress conditions during the two winter seasons (2018/19 and 2019/20) The objective of the study was to estimate the genetic variability, genetic variability, heritability and genetic advance of different quantitative characters of the forty eight chickpea genotypes under non-heat stress and heat stress conditions. The genotypes were arranged in alpha lattice design with three replicates. The characters measured were days to 50% flowering, days to 90% maturity, plant height (cm), number of pods per plant, number of seeds per plant, number of seeds per pod,100-seed weight (g), seed yield per plant (g), biomass (t ha^{-1}), harvest index and seed yield (t ha^{-1}). Most of the studied characters recorded highly significant differences (P≤ 0.01) due to genotypes, seasons and their interaction. The late sown (heat stress) reduced the seed yield, biomass and harvest index by 43.4, 36.9 and 18.5%, respectively when compared to normal sown (non-heat stress). Under non-heat stress, the genotypes no. 14, 5, 4, 34, 30 and 43 recorded the highest yield. They out-yielded the standard check Wad Hamid by 2.9, 3.7, 4.2, 6.8, 8.5 and 9.8%, respectively.

On the other hand, under terminal heat stress condition, the genotypes no. 2, 11, 4 and 27 gave the best yield and exceeded the check Merowe by 3.0, 5.8, 8.1 and 13.1%, respectively. Under non-heat stress and heat stress conditions, the phenotypic coefficient of variation (PCV) was found to be higher than the genotypic coefficient of variation (GCV) for all of the characters investigated, indicating that environmental variables influence the characters. Under non-heat stress the broad-sense heritability ranged from 19.8% (seed yield per plant) to 88.6% (100-seed weight). Under heat stress, the highest heritability coupled with highest genetic advance as percent of mean were observed for 100 - seed weight followed by days to 50% flowering and number of seeds per pod. These three traits could be used as potential selection criteria in breeding programs for developing high yielding chickpea genotypes under heat stress condition. In conclusion, this study showed that the effect of heat stress on seed yield was varied which suggested genetic variability for heat tolerance in this material.

Keywords: Chickpea, Genotypes, Variability, Heritability, Characters, Seed yield

Introduction

Chickpea (*Cicer arietinum* L.) is the third most important grain legume in the world after common bean and dry pea. The total cultivated area worldwide was estimated at about 14 million ha, producing 13 million tons (FAO, 2013). The grain of chickpea contains high protein and carbohydrate in addition to some essential minerals and vitamins.

In Sudan chickpea is traditionally grown as a winter crop in the northern part, however, its production has expanded recently to the central clay plain of Sudan. The growing season is faced by high temperatures during reproductive stage. The chickpea yields in Sudan range between 0.83 to 2.8 t/ha, depending on climatic conditions (Ahmed *et al.,* 1995).

Drought and high temperature stresses are the most important constraints among climate events. It is estimated that 50% of yield losses are caused by drought and heat stresses (Gaur *et al.,* 2012). Such changes in climate will impact chickpea production and yield and result in grain yield decreases of up to 19% in chickpea (Kadiyala *et al.,* 2016). The crop generally encounters terminal moisture and heat stresses in chickpea growing areas which lead to reduced grain yield (Gaur *et al.,* 2007). Canci and Toker (2009) studied 377 germplasm lines and 68 accessions of wild Cicer species for genetic variation and identified several heat tolerant genotypes and suggested harvest index, seed yield and pods per plant are the traits to be considered for selection.

In previous studies, various traits: number of filled pods, number of seeds, biological yield, harvest index, pod setting, and 100-seed weight were considered in understanding the heat tolerance in chickpea (Krishnamurthy *et al.,* 2011). The grain yield of chickpea under heat-stress is an important trait to assess genotypes for heat tolerance and it influence by many factors including genotype, growing season, geographical site, and agronomic practices (Tawaha *et al.,* 2005). Jha and Shil (2015) reported significant genetic variability in 30 chickpea genotypes for different phenological and yield related traits such as days to first flowering, days to 50% flowering, days to 90% maturity, total pods /plant, filled pods/plant and number of seed/plant under heat stress condition. Kumar *et al.,* (2017) recorded sufficient amount of genetic variability for various yield related traits namely seeds per pod, biological yield, 100-seed weight, and plot yield under late sown condition.

Babbar *et al.,* (2012) studied forty four promising lines of chickpea grown in RBD with three replications under late sown season. The maximum genotypic coefficient of variation was noticed for damaged pod percentage, total number of seeds per plant and total number of pods per plant. Days to 50% flowering, days to maturity, plant height, 100 seed weight and seed yield per plant showing high heritability coupled with medium genetic advance as percentage of mean, whereas, damage pod percentage, number of seeds per plant and number of pods per plant showing medium heritability and high genetic advance as percentage of mean. Mishra and Babbar (2014) studied selection strategies to assess the twelve promising chickpea promising lines under normal and heat stress environment and noticed high PCV and GCV for the traits seed yield per plant, number of effective pods per plant, number of total pods per plant, seed size and harvest index in normal and late sown environments. Flower initiation (days) and 50 % flowering (days) noted for high heritability along with high genetic advance as percentage of mean.

Sowing date is one of the most important cultural practices that result in great differences in growth and yield of grain legumes and it is usually used in farming systems to avoid heat stress, drought, pests or diseases which may occur early or late in the growing season (Khalil *et al.,* 2010).

The aims of this study were to evaluate the response of forty eight chickpea genotypes to different levels of temperature (sowing dates), based on morphological characters and to estimate the genetic variability, heritability and genetic advance for yield and yield contributing characters to identify a selection criteria for development of high yielding chickpea genotypes under non-heat stress and heat stress conditions.

Materials and Methods

2.1 Experimental sites

A field experiments were conducted for two successive winter seasons (2018/2019-2019/2020) at the farmers field in Merowe locality (Latitude: 18° 27' 0" N, Longitude: 31° 49' 59" E, Elevation: 258 meters above sea level), the Northern state of Sudan

2.2 Plant materials

The genetic materials used in this study were consisted of 14 genotypes of chickpea introduced from the International Center for Agriculture Research in the Dry Areas (ICARDA), in addition 29 genotypes introduced from International Crops Research Institute for the Semi Arid Tropics (ICRISAT). The five Sudanese chickpea varieties namely; Sheikh Mohamed, Merowe, Wad Hamid, Salwa and Hwata which released by the chickpea breeding program of the Agricultural Research Corporation (ARC) of the Sudan used a standard checks. The detailed information about the material is given in the (Table 1).

2.3 Land preparation, experimental design and cultural practices

Across two growing seasons, the land was prepared by disc ploughing, disc- harrowing, leveling and ridging. In the first season (2018/19) the genotypes was evaluated in two environments i.e., normal sown (15 November) and late sown (5 December). While in second season (2019/20) the same genotypes were grown also in two environments *i.e.,* normal sown (25 November) and late sown (15 December) under irrigated conditions. The heat stress was simulated by two sowing dates, optimum sowing (as non–stress environment) and late sowing which is considered stress environment with terminal heat stress. The experiments were arranged in 12 x 4 alpha lattice design (incomplete design) with three replications. Each replicate consisted of twelve incomplete blocks and four plots in each block. Each genotype was represented by a plot of one row (ridge). Each row was 4 m long with a spacing of 10 x 60 cm between holes and rows, respectively (40 plants per plot), giving a total plot area of 2.4 m^2 (one row x 4 m length x 0.6 m). The seeds were sown manually at the rate of 2 seeds per hole on the top of ridge. The crop was irrigated every 13 – 15 days or whenever necessary and irrigation was held three weeks before harvest. A starter dose of nitrogen in the form of urea was applied at a rate of 43 kg N/ha with the third irrigation. Weeds populations were kept to minimum by hand removal during the first month from sowing. The insecticide spinosad (Tracer 240) was used against African boll warm. The meteorological data recorded during crop growing period, (Karima metrological station) are shown in Appendix (1).

2.4 Parameters measured

During the two seasons, in any experiment the data for different characters were recorded on five competitive plants from each plot were randomly selected for recording of observations on four characters. Averages of the data from selected plants of each plot in respect of different characters were used for various statistical analyses. The data were recorded for the following vegetative and reproductive characters:-

2.4.1 Vegetative characters

(i) Days to 50% flowering: it was determined as number of days from sowing to date of flowering when about 50% of the plants of the genotype bear at least one flower.

(ii) Days to 90 % maturity: it was estimated as number of days from planting to when 90% of the plants displayed yellow, pod color, and the seed hardened in the pods.

(iii) Plant height (cm): it was measured from ground level to the top of the plant at maturity. An average of five plants was recorded in centimeters (cm).

2.4.2 Reproductive character

(i) Number of pods per plant : it was determined from five randomly sampled plants and the average value was considered.

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

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

(iv) 100 - Seed weight (g): Hundred seeds were taken randomly from each plot and weighed using a sensitive balance.

(v) 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).

(vi) 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}).

(vii) 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 (Debouck and hidalgo, 1986)

(viii) Seed yield (t ha^{-1}): This parameter was recorded after harvesting, threshing and winnowing (in g or kg). The seed yield was weighed using electronic balance on net plot basis and later converted into ton/ha for each genotype. Yield reduction percentage was calculated as follow:

% Reduction = (Ypi-Ysi) / Ypi x 100, Choukan *et al.,* (2006).

In the above formula Ysi and Ypi represent yield under heat stress and yield under non-heat stress for each genotype.

2.5 Estimate of genetic parameters

2.5.1 Phenotypic and genotypic variability

The variability present in the genotypes included the phenotypic variance, genotypic variance, phenotypic coefficient of variation and genotypic coefficient of variation were estimated according to the methods suggested by (Burton and Devane, 1953) as follows:

$\sigma^2 g = (MS1 - MS2) / r \times s$
$\sigma^2 ph = (MS1) / r \times s$

Where:

σ^2ph = Phenotypic variance
σ^2g = Genotypic variance
MS1: Mean square for genotype
MS2: Mean square for genotype × season
s = Number of season
r = Number of replication
Phenotypic coefficient of variation (PCV) = ($\sqrt{\sigma^2g}$ / x) x100
Genotypic coefficient of variation (GCV) = ($\sqrt{\sigma^2p}$ / x) x 100
Where x = population mean

2.5.2 Estimate of heritability

Heritability (H²) in broad sense for all characters studded was computed using the formula adopted by (Allard, 1960) as:

$H^2 = (\sigma^2g / \sigma^2ph) \times 100$
Where:
σ^2g = genotypic variance
σ^2ph = phenotypic variance

2.5.3 Estimate of genetic advance

Genetic advance for all characters was computed by adopting on the formulae presented by (Allard, 1960) and GA as percentage of the mean expected from selection of the best 5% of the genotypes were estimated as:

Expected genetic advance (GA) = $H^2 \times k \times \sigma^2ph$

Expected genetic advance as percentage of mean (GAM) = (GAx100)/ $\bar{x}$ Where, k is a constant value at selection intensity of 5% (k = 2.06), σ^2ph is the phenotypic standard deviation; H² is broad sense heritability; and $\bar{x}$ is the grand populations mean for the trait under considerations.

2.6 Statistical analysis

Statistical analysis of data was done using the GenStat 12th edition statistical analysis package for windows (2009). The collected data were analyzed by using the analysis of variance procedure to examine the differences among the genotypes for all measured characters. Combined analysis of variance was carried out for testing the effect of environments, genotypes and their interactions.

Table (1). Accession no. origin and status of the forty eight chickpea genotypes used in the study.

No.	Accession no.	Origin	Status	No.	Accession no.	Origin	Status
1	FLIP 09 – 181 C	ICARDA	Advanced line	20	22267	ICRISAT	Advanced line
2	LIP 09 – 179 C	ICARDA	Advanced line	21	22232	ICRISAT	Advanced line
3	FLIP 09 – 184 C	ICARDA	Advanced line	22	22223	ICRISAT	Advanced line
4	FLIP09 – 155 C	ICARDA	Advanced line	23	22235	ICRISAT	Advanced line
5	FLIP09 – 438 C	ICARDA	Advanced line	24	22366	ICRISAT	Advanced line
6	FLIP09 – 261 C	ICARDA	Advanced line	25	22293	ICRISAT	Advanced line
7	FLIP 07 – 236 C	ICARDA	Advanced line	26	22380	ICRISAT	Advanced line
8	FLIP 09 – 259 C	ICARDA	Advanced line	27	22362	ICRISAT	Advanced line
9	FLIP08 – 86 C	ICARDA	Advanced line	28	22254	ICRISAT	Advanced line
10	FLIP09 – 6 C	ICARDA	Advanced line	29	22335	ICRISAT	Advanced line
11	FLIP 08-59 C	ICARDA	Advanced line	30	22204	ICRISAT	Advanced line
12	FLIP 09-182 C	ICARDA	Advanced line	31	22272	ICRISAT	Advanced line
13	FLIP 09-187 C	ICARDA	Advanced line	32	222389	ICRISAT	Advanced line
14	FLIP09 – 240 C	ICARDA	Advanced line	33	222303	ICRISAT	Advanced line
15	22330	ICRISAT	Advanced line	34	222242	ICRISAT	Advanced line
16	22304	ICRISAT	Advanced line	35	22373	ICRISAT	Advanced line
17	22317	ICRISAT	Advanced line	36	22206	ICRISAT	Advanced line
18	22233	ICRISAT	Advanced line	37	22384	ICRISAT	Advanced line
19	22278	ICRISAT	Advanced line	38	22341	ICRISAT	Advanced line

No.	Accession no.	Origin	Status	No.	Accession no.	Origin	Status
39	22302	ICRISAT	Advanced line	44	Shiekh Mohamed	ARC, Sudan	Released variety
40	22260	ICRISAT	Advanced line	45	Merowe	ARC, Sudan	Released variety
41	22266	ICRISAT	Advanced line	46	Wad Hamid	ARC, Sudan	Released variety
42	22392	ICRISAT	Advanced line	47	Salwa	ARC, Sudan	Released variety
43	22261	ICRISAT	Advanced line	48	Hwata	ARC, Sudan	Released variety

ICARDA: International Center for Agriculture Research in the Dry Areas.
ICRISAT: International Crops Research Institute for the Semi Arid Tropics.
ARC : Agricultural Research Corporation.

Results and Discussion

3.1 Phenotypic variability

The current study indicated a wide range of genetic variability for all the measured characters under non-heat stress and heat stress conditions, as shown by their significant mean squares (Table 2). This depicted potential genetic variability and diversity in the material under consideration and improvement through conventional plant breeding methods would be possible. Under non-heat stress and heat stress conditions, seasonal (S) differences were highly significant for all the characters studied (P≤ 0.01) exception of number of seeds per pod under heat stress. While that of seasons x genotype (S x G) were significant for most of the characters studied. The wide variability shown by the different genotypes particularly for seed yield allowed the exploitation of these materials in various ways and means of selection to improve this crop. These results are in agreement with those of Yucel, (2018) who found high variability for different characters among chickpea genotypes. Wide variability has also been reported by Chopdar *et al.,* (2017) and Thakur *et al.,* (2018). Similarly, previous studies on chickpea landraces indicated significant variations for traits like plant height, days to flowering, days to maturity, number of pods per plant, hundred seed weight and seed yield (Tesfamickael *et al.,* 2014). Devasirvatham *et al.,* (2012) observed large genetic variation among 167 genotypes under heat stress.

Table (2). Mean squares for seasons, genotypes and their interaction of some agronomic characters in forty eight chickpea genotypes, combined over two seasons (2018/19 and 2019/20) under non-heat stress and heat stress field conditions.

Characters	Season (S)		Genotype (G)		S x G	
	Non-heat stress	Heat stress	Non-heat stress	Heat stress	Non-heat stress	Heat stress
DF	3953.087***	7626.125***	436.499***	306.546***	31.144***	16.444***
DM	5958.681***	4117.781***	79.255***	31.367***	37.383***	11.306***
PH	25639.80***	3141.60***	171.91***	173.96***	$54.05^{n.s}$	$94.00^{n.s}$
NPP	79119.1***	65558***	4722.9***	2484***	2322.0***	$1603^{n.s}$
NSPL	253413***	132269***	11279***	5886***	4300**	3474*
NSP	1.29471***	$0.01635^{n.s}$	0.12659***	0.14100***	$0.03848^{n.s}$	0.03416*
100-SW	728.35***	45.12*	320.34***	342.26***	$12.90^{n.s}$	$13.78^{n.s}$
SYP	55817.0***	246334.6***	528.7**	362.7***	$306.7^{n.s}$	259.8***
HI (%)	7169.03***	10734.79***	70.64***	59.55***	$34.465^{n.s}$	$19.96^{n.s}$
BIO	497209***	210087418***	335107***	$14574387^{n.s}$	$154907^{n.s}$	$8238344^{n.s}$
SY	1302774744***	247722266***	3709979**	2509221*	$1744967^{n.s}$	$1384911^{n.s}$

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 (g), 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 levels of probability, respectively.
n.s = non - significant difference at 0.05 probability level.

3.2 Genetic variability for yield related characters

The average combined values of the agronomic characteristics for the forty eight chickpea genotypes are presented in Table 3. The results show a wide range of differences, as evidenced by the characteristic ranges that include plant height (79-57 cm to 70-44 cm), number of pods per plant (216-63 to 136-48), number of seeds per pod (1.62-0.94 to 1.55-0.98), seed yield per plant (66-31 g to 51-16 g), 100-seed weight 40-13 g to 40-12 g, harvest index (37-19 to 31-16) and biomass (19.17-10.17 to 12.45-5.94) under non-heat stress and heat stress, respectively (Table 3). This signifies the presence of a wide range of genetic variability among the evaluated characteristics and highlights the genetic refinement that could be possible with the use of such a genetic pool for breeding. The number of days to 50% flowering was higher in optimum sowing date than the late sowing. The genotypes no.4, 45 and 46 were the earliest flowering under non-heat stress and heat stress conditions. On the other hand, the genotypes no. 25, 28, 33, and 37 were the latest flowering under both environments (Table 3). The genotypes no.4, 5, 7, 11 and 48 were earlier in maturity as compared to the other genotypes under the heat stress. Early maturing varieties can escape the adverse effects of heat stress on yield. Paul *et al.,* (2018) opined that higher yield under heat stress could be achieved through higher number of filled pods per plant and seeds rather than seed mass. Plant height, number of pods per plant, hundred seed weight and per cent membrane leakage at 50 days were identified as important traits under late sown environment. However, the genotypes no.20, 26, 28, 29, 33 and 42 were the latest in days to 90% physiological maturity under the same condition (Table 3). Maturity was hastened by an average of 10 days as a result of the heat stress. Similar findings were obtained by Krishnamurthy *et al., (*2011) and Neeraj *et al.,* (2012) who reported that that high temperature (late sown) causes hastening of flowering and maturity, which resulted in reduction in productivity of chickpea as compared to normal sown condition and mean of total heat requirement up to maturity of low yielding genotypes was relatively lower followed by medium and high yielding cultivar.

Under non-heat stress the plant height was varied from 58 cm to 79 cm with a genotype mean height of 67 cm. While under heat stress condition the plant height was varied from 44 cm to 70 cm with a genotype mean height of 54 cm. The shortest plant height under non- heat stress was recorded for the genotypes no. 11, 16, 23, 31 and 39. Whereas, the longest plant height under the same condition was given by the genotypes no. 3, 5, 8, 9, 10 and 13 (Table 3). Similar results were reported in previous studies by many authors (Kayan and Adak, 2012; Mallu *et al.,* 2014) in chickpea. The wide range of variation for plant height could be due to genetic, environment and genotype by environment interactions. Plant height is one of the desirable characters in chickpea which reduces lodging effect and enhance ultimate seed yield. The number of pods per plant was higher in non-heat stress than heat stress. The mean number of pods per plant was 125 for optimum sowing date and 80 for late sowing date (Table 3). The relative reduction due to late sowing date was 36%. Under non-heat stress the maximum number of pods per plant was recorded for genotypes no. 20, 22, 23, 28 and 32. In contrast, the minimum values was recorded for the genotypes no. 3, 6, 8, 9 and 12. The number of seeds per plant exhibited lower mean in late sowing than in optimum sowing. The late sowing reduced number of seeds per plant to up to 35%. Genotypes no.11, 16, 32, 37 and 38 gave the highest number of seeds per plant under heat stress. On the other hand, at the same condition, the genotypes no.1, 3, 9, 10 and 13 gave the lowest number of seeds per plant (Table 3). Under non-heat stress and heat stress conditions the highest number of seeds per pod was given by the genotypes no. 22, 24, 28 and 37 but the lowest values was recorded for the genotypes no. 2, 3, 12, 13 and18 under heat stress.

Table (3). Seed yield, yield contributing and some vegetative characters of 48 chickpea genotypes grown at Merowe under normal sown and late sown conditions, combine over two winter seasons (2018/19 and 2019/20).

No.	DF		DM		PH		NPP		NSPL		NSP	
	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late
1	50	55	119	105	74	58	114	54	153	68	1.36	1.31
2	52	54	122	110	69	62	94	71	124	80	1.12	1.07
3	60	57	125	108	75	55	89	60	99	63	1.11	108
4	46	41	114	104	66	57	123	94	140	105	1.13	1.11
5	48	48	119	105	79	62	119	62	158	78	1.26	1.34
6	60	57	124	109	68	54	88	81	97	93	1.09	1.14
7	65	59	121	105	74	58	94	59	116	78	1.19	1.17
8	68	58	125	109	75	56	88	68	97	83	1.09	1.12
9	67	59	120	109	78	70	81	58	83	67	1.03	1.10
10	70	63	125	109	75	59	102	48	133	61	1.29	1.26
11	54	54	116	105	62	55	113	136	140	158	1.24	1.14
12	49	46	117	106	71	65	63	78	68	80	1.06	1.04
13	58	55	124	109	77	58	97	49	91	50	0.94	0.98
14	52	53	122	106	72	57	130	65	180	89	1.32	1.30
15	67	61	125	108	63	52	96	61	123	77	1.27	1.26
16	62	59	127	110	58	57	114	117	156	191	1.46	1.53
17	68	62	129	106	67	49	127	67	208	98	1.62	1.47
18	54	54	127	108	75	58	132	71	156	76	1.14	1.07
19	69	61	126	108	65	52	126	61	160	72	1.26	1.19
20	58	58	126	111	70	58	164	76	180	90	1.08	1.09
21	67	61	130	105	63	54	131	91	173	115	1.25	1.30
22	69	63	129	107	63	47	191	97	279	136	1.42	1.46
23	70	61	123	109	61	53	216	109	232	146	1.22	1.35

No.	DF		DM		PH		NPP		NSPL		NSP	
	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late
24	67	61	126	109	63	50	139	85	204	123	1.46	1.48
25	72	65	124	110	66	48	132	54	163	85	1.31	1.54
26	60	57	128	111	69	53	148	108	176	137	1.21	1.29
27	68	63	127	110	70	55	129	76	160	97	1.21	1.27
28	74	69	129	112	65	44	170	49	273	79	1.60	1.55
29	67	61	123	112	68	59	117	71	148	79	1.18	1.12
30	70	62	125	110	69	53	141	75	170	89	1.20	1.23
31	66	60	126	108	61	57	107	86	124	106	1.15	1.24
32	68	61	125	107	63	48	158	111	194	156	1.26	1.43
33	76	67	129	114	59	50	95	68	118	79	1.20	1.20
34	66	62	124	108	69	53	126	96	158	134	1.23	1.39
35	68	62	124	106	67	46	126	93	166	118	1.29	1.26
36	66	62	128	109	68	48	151	98	195	143	1.30	1.52
37	72	64	123	110	58	55	107	90	158	153	1.44	1.65
38	68	62	125	107	67	51	136	118	192	152	1.38	1.24
39	63	61	121	105	62	44	133	76	192	101	1.47	1.33
40	71	62	128	108	66	52	144	67	172	76	1.18	1.14
41	68	61	129	108	64	49	128	66	206	74	1.51	1.17
42	72	63	125	111	57	44	150	99	176	135	1.18	1.24
43	57	56	126	109	64	50	151	93	210	108	1.36	1.15
44	50	39	124	105	65	56	123	85	147	104	1.22	1.24
45	47	39	120	105	68	55	125	72	143	87	1.12	1.20
46	45	40	120	107	67	61	117	107	140	129	1.20	1.24
47	53	50	118	106	65	55	128	90	148	103	1.12	1.15
48	53	50	122	104	67	56	121	77	169	100	1.33	1.28
Mean	62	57	124	108	67	54	125	80	159	102	1.25	1.26
S.E±	2.88	1.31	2.04	2.10	9.15	8.66	30.45	33.98	47.34	48.01	0.188	0.151
C.V (%)	4.6	2.2	1.6	1.9	13.5	15.8	24.3	42.1	29.6	46.8	15.0	11.9

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 and NSP: Number of seeds per pod.

No.	100-SW		SYP		BIO		HI (%)		SY		% reduction in yield
	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal	Late	
1	32	30	52	29	15.82	9.11	26	19	5.92	2.26	61.8
2	34	34	43	42	13.07	10.52	29	25	4.36	3.62	17.0
3	37	40	51	34	14.74	8.03	27	22	4.95	2.60	47.5
4	32	30	64	51	15.15	10.00	37	30	6.14	3.82	37.8
5	31	32	66	38	18.72	10.63	25	22	6.11	3.14	48.6
6	35	34	50	42	13.04	6.88	23	22	4.52	2.38	47.3
7	35	32	53	33	15.81	8.68	31	22	5.83	2.46	57.8
8	36	33	51	38	10.82	7.51	31	21	4.47	2.52	43.6
9	36	37	47	37	15.32	11.86	21	16	4.73	2.74	42.1
10	34	34	63	32	18.44	8.49	24	18	5.92	2.63	55.6
11	27	21	57	47	15.80	10.90	30	25	5.50	3.73	32.2
12	37	35	36	46	12.18	9.55	27	23	3.76	3.15	16.2
13	40	38	53	31	14.20	9.03	29	22	4.93	2.52	48.9
14	31	31	66	39	16.73	8.42	28	23	6.06	2.92	51.8
15	25	25	43	28	12.83	8.51	24	20	4.20	2.65	36.9
16	15	14	36	42	15.66	10.97	26	23	4.99	3.52	29.5
17	16	14	42	22	13.75	7.74	23	22	4.31	2.15	50.1
18	28	26	52	29	13.72	9.58	28	20	4.97	2.57	48.3
19	22	25	53	25	14.13	9.51	29	21	4.88	2.59	46.9
20	26	23	66	37	15.57	10.38	19	17	4.55	2.58	40.4
21	21	19	43	34	19.17	10.59	26	21	5.79	2.96	48.9
22	13	13	66	32	15.42	8.75	26	21	5.45	2.47	54.7
23	15	14	57	39	14.58	9.13	32	24	5.89	3.33	43.4
24	21	20	51	38	13.96	8.89	30	24	4.95	3.08	37.8
25	19	17	48	23	11.25	7.22	28	22	4.49	1.97	56.1
26	29	24	64	49	18.23	11.94	25	22	5.86	3.55	39.4
27	23	22	56	36	12.71	12.26	24	25	4.59	4.04	12.0
28	13	12	54	16	12.65	6.60	24	17	4.13	1.46	64.6
29	26	24	54	31	17.22	12.45	24	22	6.03	3.46	42.6
30	26	25	61	31	18.40	11.37	28	23	6.43	3.28	49.0
31	33	29	57	47	11.91	8.54	27	22	4.22	2.75	34.8

No.	100-SW		SYP		BIO		HI (%)		SY		% reduction in yield
	Normal	Late	Normal	Late	Normal	Late	Normal	Late	Normal (Ypi)	Late (Ysi)	
32	16	15	50	40	15.76	7.88	28	22	5.38	2.49	53.7
33	23	21	31	27	11.84	9.47	25	20	3.50	2.72	22.3
34	24	27	66	47	18.67	10.42	25	20	6.31	3.18	49.6
35	16	16	48	30	17.26	7.57	25	23	5.46	2.25	58.8
36	15	14	51	35	15.73	8.84	27	25	5.48	2.92	46.7
37	20	18	45	40	10.17	7.67	26	23	3.62	3.02	16.6
38	16	14	41	38	15.80	7.93	26	21	5.14	2.47	51.9
39	21	22	60	35	12.99	5.94	29	18	5.55	1.66	70.0
40	25	26	46	30	16.11	8.82	29	21	5.46	2.36	56.8
41	21	19	41	26	11.63	7.60	27	20	4.08	2.19	46.3
42	17	15	35	34	11.45	7.88	28	23	4.20	2.54	39.5
43	23	24	64	40	18.65	9.83	25	27	6.52	3.45	47.0
44	26	26	48	43	14.31	11.11	33	27	5.61	3.98	29.1
45	29	31	62	41	13.92	10.24	30	26	5.21	3.51	32.6
46	25	22	59	50	15.45	11.15	31	27	5.88	3.99	32.1
47	29	31	66	46	11.53	9.44	31	27	4.84	3.73	22.9
48	26	23	57	37	16.15	10.66	35	31	5.80	4.37	24.7
Mean	25	24	53	36	14.76	9.30	27	22	5.15	2.91	43.4
S.E±	3.65	3.42	16.85	10.66	4.075	3.403	5.74	4.24	1.443	1.311	
C.V (%)	14.1	13.7	31.7	29.0	27.6	36.5	20.7	18.4	28.0	45.0	

100-SW: Hundred seed weight (g), SYP: Seed yield per plant (g), BIO: Biomass (t ha^{-1}), HI (%): Harvest index and SY: Seed yield (t ha^{-1}).

The combined analysis showed that the genotypes no. 3, 9, 12 and 13 were superior to other genotypes tested with regard to 100 - seed weight at non-heat stress and heat stress conditions. In contrast, the genotypes no. 22, 23, 28, 36, 38 and 42 gave the lowest 100 - seed weight at both environments. Earlier reports in chickpea by Hakim *et al.,* (2006) and Atta *et al.,* (2008) also confirm these results. Under heat stress, the genotypes no.4, 11, 26, 31, 34 and the cultivar Wad Hamid (no. 46) obtained the highest seed yield per plant. Whereas, the genotypes no. 15, 17, 19, 28 and 33 recorded the lowest seed yield per plant under the same condition (Table 3). The mean seed yield per plant was 53 g for optimum sowing date and 36 g for late sowing date. The reduction in seed yield per plant was 32%. The genotype no. 37 sustained the lowest biomass. While, the genotype no. 5 had maximum biomass under non-heat stress condition. While genotype no. 28 recoded the lowest biomass and genotype no. 26 gave highest under heat stress. An average mean of the biomass at the non-heat stress was about 1.5 times greater than that obtained at the heat stress condition (Table 3). Under heat stress and non-heat stress the genotype no.4 and cultivars, Shiekh Mohamed (no. 44) and Hwata (no.48) gave the highest harvest index. However, the genotypes no.9, 10, 20, 28 and 39 gave the lowest harvest index under heat stress. In general, the harvest index was greater at the non - heat stress than at the heat stress, but some of the genotypes showed similar or higher harvest index under the heat stress condition. In general, the harvest index under the non - heat stress was greater than at the heat stress by an average of 18.5%.

3.3 Mean performance of genotypes for seed yield

Generally, the seed yield was reduced at the late sowing date (heat stress) which may be reasonably explained by the relatively high temperatures prevailing during flowering and pod development stages (Appendix 1). The overall mean seed yield performance of all genotypes under non-heat stress was 5.15 t ha^{-1} with a range from 6.52 t ha^{-1} (Genotype no. 43) to 3.50 t ha^{-1} (Genotype no.33). Yield decline was observed in all genotypes due to heat stress. Under non – heat stress condition, six genotypes no. 14, 5, 4, 34, 30 and 43 had performed better than the check Wad Hamid (no.46) with a seed yield advantage which ranged from 2.9, 3.7, 4.2, 6.8, 8.5 and 9.8%, respectively (Table 3). On the other hand, at heat stress the top yielder was recorded by the genotypes no. 2, 11, 4 and 27. These genotypes out - yield the check Merowe (no.45) by 3.0, 5.9, 8.1 and 13.1%, respectively. Twenty three of the tested genotypes had yield exceeding the overall mean of the trial under heat stress. Whereas, at non–heat stress also twenty three genotypes produced seed yield above the overall mean of the trial (Table 3).

The genotypes no. 27 (12.0%), 12 (16.2%), 37 (16.6%) and 33 (22.3%), exhibited lower reduction in seed yield in comparison to the best heat tolerant three checks, Shiekh Mohamed (29.1%), Wad Hamid (32.1%) and Merowe (32.6%). On the other hand, the genotypes no.39 (70.0%), 28 (64.6%) and 1 (61.8%) showed highly sensitive to heat stress as compared with the other tested genotypes (Table 3).

3.4 Genetic parameters at normal sown (non–heat stress)

The mean, genotypic variance (δ^2g), phenotypic variance (δ^2ph), genotypic coefficient of variability (GCV), phenotypic coefficient of variability (PCV), broad-sense heritability, genetic advance and genetic advance as percent of the mean for 11 traits are presented in (Table 4.) In this study the value of phenotypic variance was relatively higher than the genotypic variance for all the traits studied, indicating that there was an influence of the environment. This result was similar to that reported by Ali and Ahsan (2012) and Yaqueb *et al.,* (2010) who recorded that phenotypic coefficient of variation (PCV) was higher than genotype coefficient of variation (GCV) in all the traits indicating the effect of environment. Also similar results were reported by Sanjay Kumar *et al.,* (2019). The relative narrow gap between the phenotypic and genotypic variance values indicate the smaller contribution of the environmental effects to the phenotypic variance in the traits. Higher phenotypic and genotypic variance (23335.0%) value was recorded for seed yield (t ha^{-1}), followed by biomass (t ha^{-1}) (688.92%) and number of seeds per plant (113..52%) given in (Table 4). Considering GCV, highest GCV (1192.24%) value was noted for seed yield (t ha^{-1}). The high estimates of PCV and GCV for these characters suggested the possibility of yield improvement through selection of these characters. On the other hand, the lowest GCV value was observed by number of seeds per pod (0.246%). The effectiveness of selection in any crop depends on the extent and nature of phenotypic and genotypic variability present in different agronomic traits found in the population (Keneni *et al.,* 2011).

The current study gave high broad-sense heritability estimates (> 60%) for 100 – seed weight and days to 50 % flowering. This indicating that these characters are controlled by additive genes action which is very useful in selection. Then the moderate heritability estimates (30-60%) for number of seeds per pod, number of seeds per plant, plant height days to 90% maturity and number of pods per plant (Table 4). The highest heritability for hundred seed weight was also reported by Uday *et al.,* (2012). Whereas the lower estimation of heritability value was recorded for seed yield per plant (19.8 %), harvest index (26.2%) and biomass (27.4%). This indicated that total variability was due to genetic causes as well as due to environment. Hence, improvement for these traits through selection has limited possibility.

In the present study, estimates of genetic advance as percent of mean at 5% selection intensity ranged from 1.26% for biomass to 55.52% for 100 – seed weight. High heritability with high genetic advance as per cent of mean was recorded for 100 – seed weight, days to 50% flowering, number of seeds per plant and number of pods per plant (Table 4). Similar results were recorded by Hussain *et al.,* (2016) for 100 - seed weight. Hence, simple selection can be effective for further improvement in these characters. These results also were in agreement with that of Ali and Ahsan (2012) who recorded high genetic advance as percent of mean was observed for hundred-seed weight, number of seeds per plant and number of pods per plant.

3.5 Genetic parameters at late sown (heat stress)

Genetic parameters of yield and their components are given in Table 5. Phenotypic coefficient of variation (GCV) and genotypic coefficient of variation (PCV) across the 11 characters ranged between 0.271 – 901.83 and 30.366 –2014.85%, respectively (Table 5). Phenotypic variance was greater than genotypic variance for whole traits, indicating the influence of environmental effect. Genotypic variance decreased under heat stressed conditions compared to non-stressed conditions for characters such as days to 50% flowering, days to 90% physiological maturity, plant height (cm), number of pods per plant and seed yield per plant. PCV and GCV values of more than 20% are considered to be high, values less than 10% as low, and values between 10 – 20% as medium (Deshmukh *et al.,* 1986). Narendra, (2004) also reported greater phenotypic and genotypic coefficient of variations for the most of the characters in chickpea. Melese, (2005) also reported a wide range of variation for most of characters studied in chickpea and found PCV and GCV values of more than 54.0% and 37.48%, respectively for the biomass and grain yield. Characters like seed yield, biomass, number of seeds plant and in number of pods per plant showed high GCV and PCV (Table 5). These characters showed high genetic and environmental variation that could make selection for improvement possible. High genotypic coefficient of variation indicated the availability of high genetic variation for selection and improvement; while the lower value indicated that selection is not effective for particular character because of the narrow genetic variability Upadhaya *et al.,* 2008; Shiferaw and Kassahun 2017).

Table (4). Estimates of genetic variability parameters for different agronomic characters in 48 chickpea genotypes grown during two winter seasons (2018/19 and 2019/20) under non-heat stress (normal sown) field condition.

Characters	Mean	δ^2g	δ^2ph	GCV (%)	PCV (%)	H² (%)	GA	GAM (%)
Flowering	62	67.55	93.91	17.12	20.18	71.9	14.36	23.16
Maturity	124	6.97	20.12	5.50	9.34	34.6	3.20	2.58
Plant height (cm)	67	19.64	51.62	9.23	14.96	38.0	5.62	8.38
Pods per plant	125	400.15	1328.73	41.67	75.94	30.1	22.61	18.08
Seeds per plant	159	1163.16	2969.99	71.05	113.52	39.1	43.97	27.65
Seeds per pod	1.25	0.014	0.027	0.246	0.342	51.8	0.175	14.00
100-seed weight (g)	25	51.24	57.77	14.91	15.83	88.6	13.88	55.52
Seed yield/plant (g))	53	37.00	186.54	12.67	28.43	19.8	5.58	10.52
Harvest index (%)	27	6.03	23.01	5.11	9.99	26.2	2.59	9.59
Biomass (t ha^{-1})	14.76	30033.33	109353.49	361.04	688.92	27.4	187.09	1.26
SY (t ha^{-1})	5.15	327502	1256203	1192.24	23335.0	26.0	601.93	11.69

δ^2g: Genotypic variance, δ^2ph: Phenotypic variance, PCV: Phenotypic coefficient of variance, GCV: Genotypic coefficient of variance, H² (%): Broad sense heritability, GA: Genetic advance and GAM: Genetic advance as percent of mean.

Table (5). Estimates of genetic variability parameters for different agronomic characters in 48 chickpea genotypes grown during two winter seasons (2018/19 and 2019/20) under heat stress (late sown) field condition.

Characters	Mean	δ^2g	δ^2ph	GCV (%)	PCV (%)	H² (%)	GA	GAM (%)
Flowering	57	48.35	54.11	14.48	15.32	89.3	13.55	23.77
Maturity	108	3.34	7.83	3.80	5.82	42.6	2.46	2.27
Plant height (cm)	54	13.32	57.16	7.60	15.75	23.3	3.62	6.72
Pods per plant	80	146.83	873.49	25.24	61.57	16.8	10.23	12.79
Seeds per plant	102	402.00	1944.16	41.77	91.85	20.6	18.78	18.41
Seeds per pod	1.26	0.017	0.031	0.271	0.366	54.8	0.198	15.79
100-seed weight (g)	24	54.74	61.28	15.41	16.30	89.3	14.42	60.08
Seed yield/plant (g))	36	17.15	122.73	8.62	23.07	13.9	3.19	8.86
Harvest index (%)	22	6.59	16.24	5.34	8.39	40.5	3.37	15.34
Biomass (t ha^{-1})	9.30	1056007.16	5732723.65	2140.87	4988.14	18.4	908.56	9.76
SY (t ha^{-1})	2.91	187385.0	935344.5	901.83	2014.85	20.0	399.13	13.71

δ^2g: Genotypic variance, δ^2ph: Phenotypic variance, PCV: Phenotypic coefficient of variance, GCV: Genotypic coefficient of variance, H² (%): Broad sense heritability, GA: Genetic advance and GAM: Genetic advance as percent of mean.

Appendix (1). Monthly maximum, minimum temperature and relative humidity during two growing winter seasons.

Month	Season 2018/2019				Season 2019/2020			
	Temperature (C^0)			Relative humidity	Temperature (C^0)			Relative humidity
	Max	Min	Mean	Mean	Max	Min	Mean	Mean
Nov	32.7	18.6	25.6	28	34.4	19.8	27.1	28
Dec	28.0	13.7	20.8	31	29.3	15.0	22.2	30
Jan	29.6	13.4	21.5	27	25.7	11.0	18.4	31
Feb	30.2	15.6	22.9	24	28.7	13.7	21.2	25
Mar	32.4	16.8	24.6	20	35.2	18.3	26.8	21

Source: Karima metrological station at Northern Sudan.

Variation between phenotypic and genotypic coefficient of variations values was very low for 100 - seed weight. Similar findings were reported by Samal and Jagadev (1989). Seeds per pod, days to 90% maturity and harvest index showed low PCV and GCV values. Characters with low coefficients of variation indicate the presence of narrow genetic variation on these characters.

In addition to genetic variation, heritability of economically important traits is essential for effective breeding program and selection of specific characters. Broad-sense heritability ranged from 13.9% to 89.3%. Highest heritability was found for 100 - seed weight followed by days to 50% flowering and number of seeds per pod along with high genetic advance as percent of mean. This indicated the scope of improvement of these characters through selection. These results were in close conformity with the findings of Dasgupta *et al.,* (1992). Whereas lower estimate of heritability was recorded for seed yield per plant, number of pods per plant, biomass and number of seeds per plant, seed yield (t ha^{-1}) and plant height. The characters like the harvest index and days to 90% maturity recorded the moderate of heritability (Table 5).

Heritability alone is not a very useful measure but, together with genetic advance, it is valuable (Arshad *et al*., 2004). Genetic advance as percentage of the mean (GAM) was high for 100 – seed weight (60.08%), days to 50% flowering (23.77%), number of seeds per plant (18.41%) while low GAM was obtained for days to 90% maturity (2.27%), plant height (6.72%), seed yield per plant (8.86%) and biomass (9.76%). High heritability estimates along with high genetic advance is more helpful in predicting gain under selection than heritability estimates alone (Johnson *et al.,* 1955). According to Panse (1957) higher heritability coupled with high genetic advance as percent of mean suggest that the traits are controlled by additive gene action. Therefore, in this study, the characters such as 100 – seed weight, days to 50% flowering and number of seeds per plant, which had relatively high values of GCV, heritability and genetic advance as percentage of mean, are the most important characters which could be easily be improved through selection.

Conclusion

- Under non-heat stress and heat stress conditions, the combined analysis of variance showed there were highly significant differences among the tested genotypes for all of the characters measured, except for the biomass under heat stress, indicating the existence of variability among tested genotypes and the potential for selection under heat stress, as well as the seasons which showed highly significant differences for all characters except the number of seeds per pod under heat stress conditions.

- High temperature at late sown reduced chickpea seed yield by 43.4 %, plant height by 19.4 %, number of pods per plant by 36.0 %, number of seeds per plant by 36.8 %, seed yield per plant by 32.0%, biomass (t ha^{-1}) by 36.9% and harvest index by 18.5% as compared to normal sown, due to heat stress.

- Under non - heat stress, the genotypes no. 23, 10, 1, 29, 14, 5, 4, 34, 30 and 43 out-yielded the check Hwata by 1.5, 2.0, 2.0, 3.8, 4.3, 5.0, 5.5, 8.1, 9.8 and 11.0%, respectively. However, under heat stress condition, the genotypes no. 2, 11, 4 and 27 recorded the highest seed yield and advantage the check Merowe by an average of 3.0, 5.9, 8.1 and 13.1%, respectively.

- Under both environments, phenotypic coefficient of variation (PCV) were found to be higher than genotypic coefficient of variation (PCV) for all the characters studied. The two values differed slightly indicating less influence of the environmental factors.

- The result of genetic advance as percent of mean showed an increase of 1.26% to 55.52% and 2.27% to 60.08% magnitude made by selection under non–heat stress and heat stress field conditions, respectively.

- Characters like 100 - seed weight, days to 50% flowering and number of seeds per plant showed high broad sense heritability, high genotypic coefficient of variation and high genetic advance as percentage of the mean. These characters would be the appropriate selection criteria for higher yield potential in chickpea under non–heat stress and heat stress field conditions.

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