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Assessment of genetic variability and yield stability in chickpea (*Cicer arietinum* L.) cultivars in River Nile State, Sudan

Amel A. Mohamed[1]*, Izzat S. A. Tahir[2] and Ashraf M. A. Elhashimi[1]

[1]Hudeiba Research Station ARC. P. O. Box 31, Ed-Damer, Sudan.
[2]Gezira Research Station ARC. P. O. Box 126, Wad Medani, Sudan.

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Eight chickpea cultivars (Shendi, Jabel Marra, Wad Hamid, Atmor, Hwata, Burgeig, Salwa and Matama) were evaluated for genetic variability, yield stability and contribution of yield attributes to seed yield. Field experiments were carried out for four seasons (2007/2008, 2009/2010, 2010/2011 and 2011/2012) at Hudeiba Research Farm in River Nile State, Sudan. Randomized complete block design with six replications was used. Most of the studied traits recorded highly significant difference ($P \leq 0.01$) due to cultivars, seasons and their interaction. High heritability and low level of differences among phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for studied traits indicated that cultivars influenced more in the expression of these traits. Based on the stability analysis for seed yield; the top yielding cultivars Burgeig and Hwata were adapted to favorable conditions. Both cultivars were late in flowering and maturity and had high number of seeds plant^{-1}, biomass and harvest index. The cultivar Atmor with an intermediate seed yield was the most stable cultivar across seasons. The cultivar Salwa is optional due to its relatively high yield and large seed size. Combining farmer-preferred traits such as high and stable yield, large seed size, plant type and maturity into new cultivars will remain the main objective of the chickpea breeding program in Sudan.

Key words: Chickpea cultivars, genetic variability, yield stability, Sudan.

INTRODUCTION

Chickpea (*Cicer arietinum*) is an important pulse crop in the world as a source of diet for human and livestock and ranks third after dry bean and dry pea. Chickpea could fit well into rotation with cereal crops to improve soil fertility, prevent the build-up of diseases, insects and weeds. Chickpea is currently grown on about 12 million hectares worldwide with average annual production of 10.9 million tons (FAO, 2010). About 95% of chickpea cultivation and consumption is in the developing countries (Kassie et al., 2009).

*Corresponding author. E-mail: ameladam7@hotmail.com

The seed yield of chickpea is influenced by many factors including genotype, growing season, geographical site, and agronomic practices (Tawaha et al., 2005). Even within an environment, seasonal climatic fluctuation requires the development of cultivars with consistence performance across environments to minimize the risk of failure in unfavorable seasons.

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 central Sudan. The growing season is restricted to a short period of time by the high temperatures prevailing at the beginning and end of season. The chickpea yields in Sudan vary from 0.83 to 2.8 t/ha, depending on weather conditions (Ahmed et al., 1995). Phenotypically stable genotypes are of great importance where seasonal fluctuations are large. Although a number of cultivars have been recommended for the cultivation, information on genotypic variability, yield stability and the contribution of yield-related traits to the yield performance of chickpea cultivars are scare. Therefore, the objectives of this study were to determine the magnitude of genotypic variability for traits of interest, investigate the contribution of yield attributes in seed yield and assess cultivars yield stability and seasonal adaptation.

MATERIALS AND METHODS

Eight released chickpea cultivars (Shendi, Jabel Marra, Wad Hamid, Atmor, Hwata, Burgeig, Salwa and Matama) were evaluated for four seasons (2007/08, 2009/10, 2010/11 and 2011/12) at Hudeiba Research Farm (HRF), Ed-dammer (17° 34` N, 33° 56` E, and 350 m above sea level), located in the River Nile State, Sudan. The pedigree and a brief description of the eight cultivars are given in Table 1. Monthly data for temperature and relative humidity across seasons is illustrated in Table 2.

Sowing date was in mid-November in all seasons. Each cultivar was sown in two rows 6 m long, 0.6 m apart and 0.1 m between plants within the row. Irrigation was done every 10 days. A starter dose of nitrogen in the form of urea urea was applied at a rate of 20 kg N/ha with the third irrigation. The plots were hand weeded twice at early stages of crop cycle. The insecticide spinosad (Tracer 240) was used against African boll warm.

Data were collected on days to 50% flowering, days to 90% maturity, plant height (cm), seed yield (t ha^{-1}), biomass (t ha^{-1}) and harvest index (%). Average numbers per plant of filled pods, empty pods, seeds number, seed yield gram/plant and 100-seed weight were estimated from five randomly selected plants.

The cultivars were arranged in RCB design with 6 replicates. Separate analysis of variance for each season was performed for seed yield and its component before running the combined analysis. The mean differences were separated using Duncan′s multiple range test (DMRT). The genetic parameters and broad-sense heritability were estimated as suggested by Burton (1952) and Hanson et al. (1956).

Each season was used as a separate environment to measure stability parameters following regression analysis. Both Wricke's (1962) ecovalence (Wi) and Eberhart and Russell (1966) models were employed to investigate yield stability. General analysis was done using a computer program of GenStat 12th edition.

RESULTS AND DISCUSSION\

Genotypic variability

The tested cultivars differed significantly in all studied traits indicating their genetic variability as shown from their diverse origin. Separate analysis of variance for seed yield (t ha^{-1}) showed highly significant differences among cultivars in each season. Maximum, minimum, range, standard error, error mean square and coefficient of variation for seed yield in each season are given in Table 3. Mean seed yield varied among environments (seasons) and ranged from 1.79 t ha^{-1} in season 2010/11 to 2.38 t ha^{-1} in season 2009/10.

Mean squares of 11 traits of the eight chickpea cultivars in the four environments (seasons) are shown in Table 4. There were significant differences among cultivars, seasons and their interaction ($P \leq 0.01$) for most of the studied traits. Non-significant difference between cultivars for number of filled pods and seed yield/plant (g) was due to low genetic effect and large environmental effect. Furthermore, the non-significant difference of season X cultivar interaction for some traits indicated that the performance of the cultivars with respect to these traits was consistent across seasons.

Table 5 shows the means values of some important traits of eight chickpea cultivars across four seasons. Days to 50% flowering of the eight cultivars ranged from 38 to 48 days whereas days to 90% maturity ranged from 98 to 109 days. The cultivar Matama was the earliest in flowering and maturity, whereas Hwata was the latest in flowering and Atmor was the latest in maturity. Similar results were reported in several earlier studies that showed significant variation in days to flowering and maturity in chickpea (Atta et al., 2008; Saleem et al., 2008). Early maturity when combined with high seed yield is a desirable trait that could help to avoid terminal heat and drought and increase its adaptation in the sub-tropics (Kumar and Rao, 2001; Upadhyaya et al., 2007).

Plant height is a desirable trait to reduce lodging and enhance mechanical harvest in crops. Significant difference was observed in plant height of the eight cultivars and ranged from 47 cm for Matama to 54 cm for Atmor and Jabel Marra (Table 5). The range in plant height of the eight cultivars is narrower than the range of 30 to 70 cm reported by Gaur et al. (2010). This might be due to the selection pressure imposed in these cultivars for the desirable height for chickpea production in Sudan.

Higher number of pods, seeds and seed weight contribute to higher seed yield. Significant differences

Table 1. Cultivar pedigree and some descriptive characters.

Cultivar name	Accession No.	Year of release	Genetic background (pedigree)	Growth habit	Wilt/ root rot disease
Shendi	ILC 1335	1987	Afghanistan Selection	Semi-spreading	Susceptible
Jabel Marra	ILC 915	1993	Iran(Vysokoroshyj 30) Selection	Semi-erect	Susceptible
Wad Hamid	ICCV 2	1996	India-ICRISAT Selection	Spreading	Resistant
Atmor	ICCV 89509	1996	(L 550/Radhey)//(K 850/H 208)	Semi-erect	Resistant
Hwata	ICCV 92318	1998	(ICCV2/Surutato 77)//ICC 7344	Semi-erect	H. Resistant
Burgeig	ICCV 91302	1998	ICCC32/(K4/Chafa)	Semi-erect	H. Resistant
Salwa	FLIP 89-82c	1996	(X87TH 186/ ICCI 4198)//FLIP 82-150C	Spreading	Resistant
Matama	FLIP 91-77c	1998	(X89TH7/ILC 1245)//FLIP 82-150C	Semi-Spreading	Susceptible

Table 2. Monthly maximum, minimum temperature and relative humidity at Hudeiba Research Farm during 2007/08, 2008/2009, 2009/2010 and 201020/11 seasons.

Month	Maximum temperature (°C)				Minimum temperature (°C)				Mean relative humidity (%)			
	2007-2008	2009-2010	2010-2011	2011-2012	2007-2008	2009-2010	2010-2011	2011-2012	2007-2008	2009-2010	2010-2011	2011-2012
November	34.3	32.8	35.4	30.4	20.6	18.4	22.1	16.3	50	40	53	37
December	31.8	31.0	31.7	31.2	17.5	14.7	17.1	16.3	53	43	52	50
January	28.5	32.0	28.9	28.6	21.5	16.1	13.0	12.5	51	50	45	41
February	31.0	33.6	33.4	33.5	14.8	16.1	16.1	17.1	47	43	36	53
March	38.7	36.4	34.5	34.3	19.2	19.5	18.2	17.5	30	30	34	31

Table 3. The mean, maximum, minimum, range, error mean square, standard error and coefficient of variation for seed yield (t ha^{-1}) for four environments (seasons).

Season	Mean	Maximum	Minimum	Range	EMS	5%LSD	SE±	CV%
2007/08	1.82	1.99	1.72	0.27	0.084^{**}	0.3397	0.118	15.9
2009/10	2.38	2.74	1.93	0.81	0.146^{**}	0.3397	0.156	16
2010/11	1.79	2.02	1.46	0.56	0.192^{**}	0.3397	0.179	24.5
2011/12	1.92	2.47	1.71	0.76	0.072^{**}	0.3397	0.11	14

were found among cultivars in number of seeds/plant, number of empty pods and 100-seed weight (Table 5). The cultivar Jabel Marra attained the highest number of seeds per plant but the lowest 100-seed weight. Conversely, the two cultivars Matama and Salwa were recorded the lowest number of seeds per plant but had the highest seed weight. This explained the strong negative correlation between the two traits (r = -0.876, P< 0.01). The empty pods ranged from 14 pods per plant for Hwata to 7 pods per plant for Matama. Generally, the high yielding cultivars showed high number of empty pods.

Cultivars differed significantly in biomass production (Table 5) as reported by other investigators (Arshad et al., 2004; Jeena et al., 2005). The three top yielding cultivars (Hwata, Burgeig and Jabel Marra) gave the highest biomass indicating the high contribution of this trait to seed yield of these cultivars. Significant difference was found among cultivars in harvest index (Table 5). The highest harvest index was recorded by Matama cultivar indicating its efficiency in translocation of assimilates for seed yield despite its earliness. The significant correlation with seed yield (r = 0.794, P = 0.016) suggested the importance of harvest index as a key selection trait as reported earlier (Krishnamurthy et al., 2011) especially under heat stress conditions.

Genetic parameters for yield and its components are given in Table 6. Phenotypic coefficient of variability

Table 4. Mean squares of yield and some yield components for eight chickpea cultivars evaluated for four seasons (2007/2008, 2009/2010, 2010/2011and 2011/2012).

Trait	Season(df = 3)	Genotype(df = 7)	Seas.xGen.(df = 21)	Pooled error(df = 140)
Days to 50% flowering	138**	375**	50.1**	8.99
Days to 90% maturity	863**	239**	72.2**	22.2
Plant height	4896**	150**	26.0ns	21.2
Number of full pods	2675**	539ns	272ns	273
Number of empty pods	1080**	139**	47.9**	19.3
Number of seeds/plant	2847**	1806**	376ns	352
100-seed weight (g)	42.2**	545**	5.76**	2.07
Seed yield/plant(g)	93.8**	19.7ns	17.0ns	11.5
Biomass (t ha^{-1})	3.35ns	1.48**	2.01**	0.61
Harvest index (%)	0.09**	0.02**	0.007**	0.003
Seed yield (t ha^{-1})	3.68**	0.89**	0.41**	0.123

Table 5. Means of some vegetative and reproductive traits for eight chickpea cultivars evaluated for four seasons (2007/2008, 2009/2010, 2010/2011and 2011/2012).

Cultivar	Days to 50% flowering	Days to 90% maturity	Plant height (cm)	Biomass (t ha^{-1})	Harvest index (%)	Filled pods number	Empty pods number	No. of seeds /plant	100-Seed weight	Seed yield g/plant
Shendi	46[b]	104[c]	51.6[ab]	5.28[bc]	0.339[cd]	49[ab]	12[ab]	59[ab]	19.4[e]	10.4[ab]
Jabel Marra	42[c]	104[bc]	53.8[a]	5.66[ab]	0.358[bc]	51[a]	10[bcd]	65[a]	17.3[f]	10.7[ab]
Wad Hamid	38[d]	107[ab]	49.9[bc]	5.38[bc]	0.320[d]	44[ab]	8[de]	48[bc]	24.7[c]	10.0[b]
Atmor	42[c]	109[a]	53.8[a]	5.34[bc]	0.360[bc]	48[ab]	9[cde]	61[a]	18.8[e]	10.8[ab]
Hwata	48[a]	107[abc]	50.6[bc]	5.57[abc]	0.396[a]	52[a]	14[a]	61[a]	22.5[d]	12.5[a]
Burgeig	47[b]	107[ab]	51.9[ab]	5.90[a]	0.380[ab]	53[a]	12[abc]	56[ab]	23.9[c]	12.1[ab]
Salwa	46[b]	104[c]	48.6[cd]	5.43[abc]	0.361[bc]	44[ab]	12[ab]	44[c]	31.9[a]	12.0[ab]
Matama	38[d]	98[d]	46.6[d]	5.10[c]	0.397[a]	40[b]	7[e]	42[c]	26.4[b]	10.8[ab]
Mean	44	105	50.9	5.46	0.364	48	10.5	55	23.1	11.2
SE±	0.61**	0.96**	0.94**	0.16*	0.011**	3.37NS	0.896**	3.83**	0.29**	0.69[NS]
5%LSD	1.71	2.69	2.63	0.45	0.031	9.43	2.51	10.7	0.82	1.94
CV%	6.9	4.49	9.05	14.4	14.3	34.8	41.8	34.3	6.2	30.4

*, ** Significant at 0.05 and 0.01 levels of probability, respectively; NS= non-significant. Means followed by the same letter (s) within each column are not significantly different at 0.05 according to DMR

was slightly higher than genotypic one for all traits. High heritability estimates were recorded for all studied traits except biomass. These high estimates of heritability for the traits under consideration indicated that a reasonable proportion of the total variability was due to genetic causes. Khan et al. (2011) and Saleem et al. (2008) found similar results and observed high heritability values in chickpea for days to flowering, plant height and 100-seed weight. Estimates of genetic advance suggested that number of seeds $plant^{-1}$, 100-seed weight, and days to 50% flowering were important traits to select for high yield.

The potential of the crop to respond favorably to breeding programs depends upon the nature and magnitude of the variability. The yield potential of the two cultivars Burgeig and Hwata can be explained based on the high values for full pods number, number of seeds per plant, biomass, tall height and late maturity. The two cultivars were land races introduced from ICRISAT. The two cultivars Salwa and Matama recorded considerable seed yield, high large seed, early flowering and maturating and had the shortest plant height. Both cultivars were land races introduced from ICARDA. Depending to these different traits and due to their origin the cultivars could be cluster in two diverse groups.

Table 7. Analysis of variance for stability for seed yield (t ha^{-1}) of eight chickpea cultivars evaluated across four environments.

Source of variation	DF	SS	MS	F	Percent explained
Genotypes (G)	7	6.25	0.893	7.23**	24.1
Environment (E)	3	11	3.68	7.53**	42.54
GE interaction	21	8.66	0.412	3.34**	33.4
Environment (Linear)	1	11	11	22.6**	
GE interaction (Linear)	7	4.21	0.601	4.87**	
Pooled deviation	14	4.45	0.318	2.57**	
Pooled error	140	17.3	0.124		
Total	191	53			

**Significant at 0.01 levels of probability.

Table 8. Mean yield, regression coefficient (bi), deviation from regression (s^2_{di}) and ecovalance (Wi) on seed yield (t ha^{-1}) of eight chickpea cultivars evaluated across four environments.

Cultivar	Mean	bi	s^2_{di}	Wi
Shendi	1.770[cd]	0.05	0.038	0.284
Jabel Marra	1.999[b]	0.27	0.139	0.401
Wad Hamid	1.709[d]	1.51	0.05	0.16
Atmor	1.922[bc]	0.66	0.035	0.096
Hwata	2.224[a]	1.85	0.04	0.247
Burgeig	2.261[a]	1.45	0.045	0.135
Salwa	1.970[bc]	1.48	0.017	0.087
Matama	1.950[bc]	0.73	0.008	0.034
Mean	1.976			

Means followed by the same letter (s) within each column are not significantly different at 0.05 according to DMRT.

Yield satiability

Analysis of variance for stability showed highly significant differences for seed yield among genotypes (G), environments (E) and their interactions (GEI) (Table 7). From the total sum of squares due to treatments (G + E + GEI), environment attributed the highest proportion of the variation (42.5%), followed by genotype x environment interaction (33.4%), whereas genotype contributed 24.1% of total variation. The sum squares due to environments and genotype x environment were partitioned into environments (linear), genotype x environment (linear) and deviations from the regression model. The significance of these components showed that both predictable and unpredictable (seasons) components shared G x E interaction. The G x E (Linear) interaction was highly significant which demonstrated that genotypes responded differently to various environmental conditions in agreement with that reported earlier in chickpea (Arshad et al., 2003; Bakhsh et al., 2006; Prakash, 2006).

The mean seed yield of the eight chickpea cultivars ranged from 2.3 t ha^{-1} for Burgeig to 1.7 t ha^{-1} for Wad Hamid. According to Eberhart and Russell (1966), both the linear (bi) and non-linear (s^2_{di}) are needed for judging the stability of a genotype. The stable genotype would be the one with high mean yield, low regression coefficient (bi=1) near unity, with non-significant deviation from regression ($s^2d=0$). Regression values above unity (>1) describe genotypes specifically adapted to high yielding conditions whereas genotypes with slope less than one (<1) are sensitive to change in environment and are therefore, better adapted to poor environments (Finlay and Wilkson, 1963). Moreover, Wricke (1962) reported that the low values of Wi are indicative of high stability. The regression coefficients (bi values) ranged from 0.05 to 1.85 for seed yield (Table 8). This large variation indicated the differential responses of cultivars to seasonal variations. The two cultivars Mattama and Atmor recorded high seed yield, regression coefficient close to unity with non-significant deviation from regression coefficient and low values of ecovalance (Wi) indicating their stability across seasons.

Salwa cultivar showed similar results, however, it had a regression values above unity (bi= 1.5) indicating its adaptation to high yielding conditions. The two cultivars with the highest seed yield, Burgeig and Hwata showed regression (bi) value more than unity and non-significant deviation from regression indicating their specific adaptation to favorable environments. On the other hand, Jabel Marra had high seed yield but regression coefficient less than unity and non-significant s^2_{di} values indicating that the cultivar could be considered as adapted to unfavorable conditions.

Conclusion

The high genotypic variation observed in most of the studied traits coupled with high broad sense heritability estimates indicated the genetic influence and hence the possibility of genetic improvement in the traits under consideration. The cultivars used in this study showed different levels of stability across different environments. Atmor had stable yield across seasons, therefore it could be tested over locations for stability verification and for further use in breeding program. The two cultivars Burgeig and Hawata were adapted for favorable conditions and are recommended for farmers in the favorable production areas. Salwa could be a farmer-preferred cultivar due to its relatively high seed yield and large seed size. Performance of high yielding cultivars associated with high harvest index, this suggests the importance of harvest index as key selection traits.

Conflict of Interest

The authors have not declared any conflict of interest.

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