

Full Length Research Paper

Yield performance of chickpea (*Cicer arietinum* L.) genotypes under supplemental irrigation regimes in semi-arid tropics

Ruth Muruiki¹, Paul Kimurto^{1*}, Bernard Towett¹, Gangarao Rao²

¹Department of Crops, Horticulture and Soils, Egerton University, P. O. Box 536-20115 Egerton, Kenya.

²International Crops Research Institute for the Semi-arid Tropics (ICRISAT), P. O. Box 39063-00623 Nairobi, Kenya.

Received 2 April, 2020; Accepted 2 February, 2021

Chickpea (*Cicer arietinum* L.) grown in the semi-arid environment is not usually irrigated. Knowledge about effect of reduced drought stress effects under supplemental irrigation can improve chickpea productivity. In this study, the chickpea has been submitted to supplemental irrigation during reproductive phase under rainfed conditions. The main objective was to determine the effects of supplemental irrigation regimes on grain yield performance and associated grain yield traits of selected chickpea genotypes under grown in the field conditions in arid and semi-arid areas of Kenya. Different genotypes were evaluated at Kenya Agricultural and Livestock Research Institute (KALRO-Pekerra, Marigat), Baringo county. The trial design was split plot design in randomized complete block design (RCBD) in three replicates. Various parameters were measured. There was significant differences in the test genotypes ($p < 0.05$) and traits measured with better performance with reduced drought stress due to supplemental irrigation. However, there was a high reduction among high yielding genotypes. The use of stress tolerance indices enabled identification and grouping of test genotypes into 4 with varied responses to yield losses to stress and no-stress conditions. Genotypes ICCV 00108, ICCV 92318 and ICCV 92944 are suitable for supplemental irrigation to maintain high potential yield, while ICCV 97105, ICCV 97306 and Cavir could be recommended for production under rainfed conditions. Genotypes ICCV 92318 and ICCV 97306 could be recommended for further evaluation and final release to farmers for commercial production.

Key words: Irrigation, chickpea, genotypes, drought stress indices, tolerance.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is the third most important pulse crop in the world, after dry beans and field pea (Mallu et al., 2015), with a total production of 14.2 million tons from an area of 14.8 million ha and a productivity of 0.96 t ha⁻¹ (FAOSTAT, 2014). Chickpea is highly valued

for its nutritional quality and health benefits and ability to improve soil fertility and sustainability of the cropping systems. It is also considered as a high energy and protein feed in animal diets (Bampidis and Christodoulou, 2011).

*Corresponding author. E-mail: maaroufbrahim@gmail.com.

Chickpea is largely grown as a rain fed crop in the arid and semi-arid environments in Asia and Africa, where more than 80% of the annual rainfall is received during the preceding long rainy season (Kumar and Abbo, 2001). In these regions the rainfall variability is usually high, leading to varying amounts of water storage in the soil and varying intensities of drought stress. Such growing condition imposes increasing intensities of water deficit as the crop cycle advances, leading to a severe water deficit at reproductive phase and crop maturity. Ludlow and Muchow (1990) and Saxena (2003) noted that these types of receding soil water conditions impose a ceiling on the cropping duration demanding selection for matching duration varieties for the best adaptability and productivity.

Drought stress is a major constraint to agricultural production in many developing countries of the arid and semi-arid regions of the world (Golbashy et al., 2010). Globally, water scarcity is increasingly becoming a major limitation for agricultural production and food security in sub-Saharan Africa (Turner et al., 2001). For example, in East Africa as in most parts of the tropics, rainfall patterns are of erratic nature causing drought stress at virtually any stage of plant growth. Thus, soil moisture stress towards end of the crop season (terminal drought) is the most important abiotic stress in about two-thirds of the global chickpea area. Varieties with improved drought avoidance (dehydration postponement) and/or drought tolerance (dehydration resistance) are needed for improving grain yield under drought stress (Gaur et al., 2007).

In the Kenyan drylands, drought stress is the leading crop production constraint. Drought stress causes 30-45% yield reduction of major crops like maize, beans, wheat and even chickpea annually in marginal areas of during drought periods (Kimurto et al., 2009, 2013). Similarly, in semi-arid tropics, chickpea is mainly cultivated in the arid and semi-arid tropical regions under rain-fed condition and hence it is susceptible to terminal drought and heat stress due to decreased rainfall and depletion of stored soil moisture towards maturation, and experiences up to 50% yield loss (Ahmad et al., 2006; Gaur et al., 2013; ICRISAT, 2012).

Although irrigation to reduce water deficit may be an option, it may not be feasible in this ASALs areas due to scarcity of water sources, since water supplied by rivers and/or streams compete from animals and human for domestic use. Furthermore, establishment of irrigation schemes need for large capital outlay for effective coverage. However, in winter-sown chickpea, Zhang et al. (2000) noted that limited supplemental irrigation can, however, play a major role in boosting and stabilizing the productivity. Chickpea has a strong indeterminate growth habit and when growing conditions are favourable the plant continues vegetative growth without setting pods or filling few pods (Liu et al., 2013). Management options such as supplemental irrigation can be deployed to

modify or minimize the detrimental effects of drought to some extent (Soltani et al., 2000).

Rosielle and Hamblin (1981) suggested that the presence of genotype \times environment interactions reduces the efficiency of using grain yield as the sole selection criterion and, thus, complicates the efforts of selection. In this regard, other selection criteria also known as stress tolerance indices have been used for genotypes selection based on the performance in stressed and non-stressed conditions. These include among others like the tolerance index (TOL), stress tolerance index (STI), geometric mean productivity (GMP), mean productivity index (MP), drought susceptibility index (DSSI), tolerance index (TOL) and harmonic mean productivity (HMP) have been proposed to be calculated on the basis of grain yield in most studies (Rosielle and Hamblin, 1981; Fernandez, 1992; Schneider et al., 1997; Fischer and Maurer, 1978). They noted that the greater the TOL value, the larger yield reduction under drought stress conditions and the higher drought sensitivity. However, Rosielle and Hamblin (1981) and Fernandez (1992) noted that this may not be the case always. For example, research findings reported by Farshadfar et al. (2014) noted that a selection based on minimum yield reduction under stress conditions in comparison with non-stress conditions (TOL) failed to identify the most tolerant genotypes in chickpea in Iran. Similarly, Hamblin (1981) reported that selection based on the tolerance index often leads to selecting cultivars which have low yields under nonstress conditions. The greater SSI and TOL values, the greater sensitivity to stress, thus a smaller value of these indices is favoured.

Another important index is using correlation analysis to determine the relationship between yield and yield attributing traits such as morphological characteristics which is the basic prerequisite for indirect selection of high yielding chickpea varieties (Mallu et al., 2015). Correlation analysis of chickpea germplasm can provide information for selection of best plant materials for production or for breeding and therefore would assist in future breeding strategies for drought tolerance in drylands (Malik et al., 2009). For example Malik et al. (2010) reported that traits with positive and significant correlation with seed yield can be used for indirect selection of high yielding genotypes. The correlation between most drought tolerance indices mainly TOL, STI, GMP and DSSI of 64 chickpea accessions had significant correlation with each other. They noted that all of tolerance indices except $YI \times YP$, $SSI \times STI$, $HMP \times TOL$ and $YI \times TOL$ showed significant positive correlation and all of these indices except $SSI \times TOL$ and $SSI \times YP$ had significant negative correlation with SSI index in complementary irrigation condition. In contrast, under dryland conditions, all of tolerance indices except $SSI \times TOL$ had significant negative correlation with SSI index and the rest of indices except $TOL \times YS$, $HMP \times TOL$ and $YI \times TOL$ which showed positive correlation.

In related studies, Farshadfar et al. (2014) reported that

DSSI had negative and significant correlation with TOL index in the rainfed stress conditions and but had a positive correlation under non-stress rainfed conditions. Further HMP index with the GMP and STI indices had a significant and positive correlation. In related studies, Ghasemi and Farshadfar (2015) reported similar findings in chickpea in Syria. In related study Mitra (2001) reported that, drought indices provide a measure of drought based on loss of yield under drought conditions in comparison to normal conditions not only have been used for screening drought-tolerant genotypes, but also can help to find the best agronomic treatments or genotype to coping drought stress. These indices are either based on stress resistance or susceptibility of genotypes (Fernandez, 1992). It has been reported that the wheat variety Hashim-8 which indicated higher mean productivity (MP), Geometric mean productivity (GMP) and stress tolerance index (STI) whereas stress susceptibility index (SSI) and tolerance (TOL) was observed at its lowest. In this and other related studies, MP, GMP and STI were recognized as beneficial drought tolerance indicators for selecting a stress tolerant in wheat variety (Khakwani et al., 1992; Sio-Se, 2006; Drikvand et al., 2012).

However, Clarke et al. (1992) noted that to achieve these, to achieve better genetic gains and improve plant drought tolerance through enhancing the traits that are linked to drought tolerance. There is need for evaluation of wide genetic-based germplasm both under stressed and optimum moisture levels to identify elite materials for subsequent detailed investigation into genetic, and physiological basis of drought tolerance mechanisms. Breeding strategies would be enhanced by management options such as supplemental irrigation (Soltani et al., 2000), to better reduce the detrimental effects of drought, especially in ASALs areas where there is water scarcity that coincide with moisture-sensitive periods in chickpea. Several studies have reported that flowering and grain filling is the most sensitive to drought stress (Ravi et al., 1998; Reddy and Ahlawat, 1998) and suggested as the critical time for irrigation. In contrast, Ramakrishna and Reddy (1993) demonstrated a seed yield reduction of more than 50% in chickpea when they were irrigated during vegetative stage due to excess vegetative growth, which leads to lodging. In Semi-arid tropics (SAT) especially Kenya, there is limited information on the contribution of supplemental irrigation of ameliorating the effects of drought stress during flowering stage and effect on yield and productivity of chickpea genotypes. The present study aimed to investigate the effect of supplemental irrigation during flowering stage on the phenology, plant growth, seed quality and yield of short-rain sown chickpea in semi-arid areas of the Rift Valley, Kenya. Furthermore, knowledge of the quantitative response of chickpea to drought stress can be used in irrigation scheduling on timing and amount of water supply for maximum profit.

MATERIALS AND METHODS

Experimental site description

Location

The study was conducted at Kenya Agricultural and Livestock Research Institute (KALRO-Pekerra). Both sites are located in Marigat division, Baringo county. The site lies at a latitude of 1°45' N and longitude 36°15' E with an altitude 1067 m above sea level. The site is classified in the lower midland agro-ecological zone (LM V) (Ondieki et al., 2013; KARI, 2009).

Temperature and rainfall

The mean maximum, mean minimum and extreme maximum temperatures are: 32.4, 16.8, and 37.7°C, respectively (Jaetzold and Schmidt, 1983). The area receives between 700 and 950 mm of rainfall per annum, with peaks in the April/May and July/August rain seasons. The soils are volcanic fluvisols of sandy/silty clay loam texture, slightly acid to slightly alkaline, highly fertile with adequate, Potassium, Phosphorus, Calcium, Magnesium but low Nitrogen and Carbon. Annual rainfall mean is 654 mm and almost double the Evapo-transpiration (ET) of 1,360 mm (Ondieki et al., 2013; KARI, 2009).

Plant

The genotypes evaluated included four released varieties in Kenya: "Chania Desi 1" (ICCV 97105), "LTD 068" (ICCV 00108), "Chania Desi 2" (ICCV 92944) and a local germplasm commonly referred to as "Ngara local". Three advanced lines (ICCV 92318, ICCV 97306 and ICC 3325), two drought susceptible checks (ICC 283 and ICC 1882), one drought tolerant check (ICC 4958) and CAVIR a Spanish variety.

Experimental designs

The experiment conducted during August/November cropping season (2013/2014). The trial design was split plot design in randomized complete block design (RCBD) in three replicates. The main plot was water regimes (rainfed-RF and supplemental irrigation-IRR) while subplots were test genotypes.

Under rainfed conditions, genotypes were planted under normal rainfall received during the cropping season. Supplemental irrigation treatments (IRR) was applied through furrows to near field capacity (FC-using gravimetric method) at flowering, podding and grain filling at 10 days interval to reduce moisture stress during critical reproductive stage.

The genotypes were spaced 30 cm × 10 cm, giving a plant density of approximately 25 plants m². The crops were routinely sprayed with insecticide to prevent damage from *Helicoverpa armigera*. Weeds were mechanically controlled every one week.

Temperature and rainfall measurements

During the course of the experiment, temperature and rainfall measurements were taken from the Meteorological station at Perkerra Irrigation scheme. During this period, the highest average temperature was recorded in December, January and February (36, 33 and 38°C, respectively). From March up to July, the temperatures steadily decreased up to about 23°C. From August to November the recorded temperature was 24 to 29°C. The average

mean temperature recorded during the cause of the experiment was 27.5°C.

The crop received a total of 204 mm during cropping season between August-November, while total annual rainfall was received in the site was 515 mm.

Data taken

Yield and yield components

Five plants were randomly selected from the middle of the plot for the measurement of yield components. Plant height (cm) measured at maturity from the base of the plant to the top of the main shoot; 100-seed weight (g) as weight of 100 seeds after harvest; biomass yield (g one meter plot⁻¹) as the weight of above ground shoot; canopy diameter (cm) as distance of canopy in cm; harvest index (HI) as ratio of seed yield to biological yield and grain yield (recorded as grain yield from 1 m plot after harvesting, then dried to 13% moisture content and converted to kg ha⁻¹).

Determination of drought tolerance selection indices

Further evaluations of the test genotypes, other selection indices were introduced, namely:

- (1) Stress Tolerance Index (STI) (Fernandez, 1992)
- (2) Mean Productivity (MP) (Rosielle and Hamblin, 1981)
- (3) Geometric Mean Productivity (GMP) (Fernandez, 1992)
- (4) Stress Tolerance (TOL) (Rosielle and Hamblin, 1981)
- (5) Drought susceptibility Index (DSSI) (Fisher and Maurer, 1978)
- (6) Stress Intensity (SI) (Bouslama and Schapaugh, 1984)
- (7) Yield Stability Index (YSI) (Bouslama and Schapaugh, 1984)
- (8) Yield Index (YI) (Gavuzzi et al., 1997)

Tolerance indices were calculated on the basis of grain yield under stress (rainfed) (GYs) and non-stress conditions (irrigated) (GYp). Drought susceptibility index (DSSI) was calculated as $[1 - (GYs/GYp)] / [1 - (G\check{Y}s/G\check{Y}p)]$ (Fischer and Maurer, 1978); where GYp is mean yield of each cultivars under supplemental irrigation (non-stressed) conditions, Ys is mean yield of each cultivar under rainfed (stressed) conditions, G \check{Y} p mean yield of all cultivars under irrigated (non-stressed) condition and G \check{Y} s mean yield of all cultivars under rainfed (stressed) condition. Stress tolerance index (STI) was obtained by dividing the product of GYp and Ys with squared value of G \check{Y} p as $STI = (GYp)(GYs)/(G\check{Y}p)^2$. The Tolerance index (TOL) was obtained from the difference in yield loss from non-stressed (GYp) and stressed conditions (Yp) as: $TOL = (GYp - GYs)$. The greater the TOL value, the larger yield reduction under drought stress conditions and the higher drought sensitivity of the genotype. Stress intensity experienced by genotype is classified into mild, moderate and severe. Stress intensity is mild when yield reduction is between 0 and 25%, moderate when yield reduction is situated between 25 and 50% and severe when yield reduction is between 50 and 100%. The mean productivity (MP) was obtained from average yield of stressed (Ys) and non-stressed conditions (YP) as $MP = (GYs + GYw)/2$. The geometric mean productivity (GMP) was determined as a relative performance as square root of the product of yield under stress (GYs) and non-stress conditions (GYp) as $GMP = \sqrt{(GYs) \times GYp}$. GMP gives indication of severity of yield loss under variable fields over season and years (Ramirez-Vallejo and Kelly, 1998; Fernandez, 1992).

Data analysis

Data analysis was performed by GenStat (14th edition) statistical

software. The means were separated by Tukeys at $P < 0.05$. Pearson's correlation coefficient ($P < 0.05$) was used to determine the correlation among the measured traits. Values and means from calculation of drought tolerance selection indices were tabulated and compared for each genotype.

RESULTS

Effects of irrigation (water) regimes on yield and yield components

The results for the analysis of variance (ANOVA) showed that there were significant differences ($P < 0.05$) in the genotype, water regimes (supplemental irrigation and rainfed condition) and genotype \times water regimes ($G \times W$) interaction among test genotypes and traits measured (Table 1). The presence of $G \times W$ interaction shows that genotypes response to varying water supply was varied across the water treatment. Traits also responded differently under both rainfed and supplemental irrigation (Tables 2 and 3). There was significant interactions ($P < 0.05$) between water regime and genotype effects on days to 50% flowering (DF).

When supplemental irrigation was introduced during flowering (reproductive stage) all the yield and yield components were increased traits increased by 9 to 60% (Table 2) as compared to rainfed conditions.

It should also be noted that under rainfed conditions, early maturing genotypes like ICCV 92944, ICCV 97105 and ICC 4958 took a mean of about 80 days to mature while under supplemental irrigation (not measured) was applied the mean maturity periods for these early maturing genotypes was 88 days. Similarly the late maturing genotypes (ICC 3325, Cavor, ICC 1882) took between 97 and 101 days under rainfed conditions and maturity was extended by 3 to 10 days (101-110 days) when supplemental irrigation was added.

Overall biomass varied from 1247 to 3403 kg/ha under rainfed condition as compared to from 1702 to 4000 kg/ha under supplemental irrigation. It is the finding of this study that there are significant genotypic responses when supplemental irrigation was applied. For example, late maturing genotypes like ICC 283 accumulated more biomass (up to 4000 kg/ha) when supplemental irrigation (IRR) was added later in the growing season compared to its accumulation of 3404 kg/ha under rainfed conditions. Under rainfed conditions susceptible genotypes had low biomass accumulation over the entire growing period as compared to tolerant genotypes (Table 3).

There was an increase in canopy spread (CS) by about 15% (means of 45.6 to 52.2 cm) as compared to rainfed conditions. Under rainfed condition, canopy spread (CS) ranged from 43.32 cm (ICC 283) to 52.4 cm (ICC 4958). The lowest CS ranged between 32.8 and 41.0 (ICC 3325 and ICC 283, respectively) while greatest CS ranged between 55 and 57.3 cm (ICCV 92318, ICCV 00108 and ICC 4958). Drought tolerant genotype, ICC 4958 had 30

Table 1. Mean squares for yield and yield components under irrigated and non-irrigated conditions in Marigat.

Source of variation	d.f	Biomass (kg/ha)	Canopy Spread	Plant height (cm)	Harvest Index	100 seed weight (g)	Yield (kg/ha)
Genotype	10	3,374,033***	353.41*	178.22**	0.046***	285.85***	393,961***
Site	1	1,727,621***	990.44**	961.89**	0.00	133.26***	284,610**
Genotype x site interaction	10	22,181**	7.52***	16.88***	0.00	1.88**	2,590
Error	42	10,680	1.722	4.531	0.004	0.87	50,093
Total	63						
CV%		5.2	2.9	5.2	22	5.3	27.6
I.s.d. _{0.05} G		120.4	1.53	2.48	0.07	1.09	260.8
I.s.d. _{0.05} S		51.3	0.65	1.058	0.03	0.46	111.2
I.s.d. _{0.05} G.S		170.3	2.16	3.507	0.11	1.54	368.8

G- Genotype, WR- Water regime (supplemental irrigation and non-irrigated); GW- Genotype x water regime interaction. *, **, ***P<0.1, 0.05, and 0.001 significance levels, respectively

Table 2. Means for yield, yield components and the effects of supplemental irrigation in Marigat, Baringo county.

Parameter measured	Rainfed condition (RF)	Irrigated water regime (IRR)	% increase due to supplemental irrigation
Days to flowering	48.0	59.0	22.92
Days to Maturity	88.0	96.0	9.09
Canopy spread (cm)	45.6	52.5	15.13
Biomass (kg/ha)	1998.8	2551.6	27.66
Plant height (cm)	44.3	55.3	24.83
100-seed weight (g)	18.2	23.2	27.47
Grain yield (kg/ha)	839.5	1348.5	60.63
Harvest Index	0.44	0.55	25.00

and 6% higher CS than drought susceptible genotypes ICC 283 and ICC 1882, respectively. On average, ICCV 92318 had the highest CS (57.3 cm) among the released varieties followed by ICC 4958 and ICCV 00108, which increased to over 50 cm for these genotypes when supplemental irrigation was applied (Table 4). The results showed that there was about 24.8% mean increment (from 44.3 to 55.3 cm) due to supplemental irrigation in the plant height (PH). Under rainfed condition, plant height ranged from 35.0 cm (ICC 283) to 53.0 cm (ICCV 92318). The lowest PH ranged between 35.0 and 39.1 cm (ICC 283 and ICC 1882, respectively), while greatest PH ranged between 50.7 and 53.0 cm (ICCV 00108, CAVIR and ICCV 92318) (Table 3).

Drought tolerant genotype, ICC 4958 was 28.6 and 8% higher PH compared to the drought susceptible genotypes, ICC 283 and ICC 1882, respectively under rainfed conditions. On average, ICCV 92318 had the highest PH (53.0 cm) among the released varieties followed by CAVIR and ICCV 00108, which increased to over 50 cm for these genotypes when supplemental irrigation was applied (Table 3).

Overall, above 100 seed weight was increased by

27.4% under supplemental irrigation from an average of 18.2 g to 23.2 g (Table 3). Large genotypes such as CAVIR, ICCV 92318 and ICCV 97306 attained above 30 g compared to small seeded genotypes when supplemental irrigation was added later in the growing season (Table 4). Drought tolerant genotype, ICC 4958 was 54.4 and 61.5% higher 100 seed weight compared to the drought susceptible genotypes, ICC 283 and ICC 1882 respectively (Table 4). Overall 100-seed weight varied from 9.0 to 26.0 g under rainfed condition to 15.7 to 33.6 g under supplemental irrigation (Table 3).

Similarly, supplemental irrigation increased grain yield by about 60.3% (means of 839.5 to 1348.5 kg/ha) as compared to rainfed conditions (Table 3). Under rainfed condition, grain yield (GY) ranged from 505 kg/ha (ICC 1882) to 1001 kg/ha (ICCV 97306). The lowest GY ranged between 505 and 669 kg/ha (ICC 1882 and ICC 3325, respectively). The greatest grain yield recorded above 900 kg/ha was from commercial lines (ICCV 92944, ICCV 92318, ICCV 97105 and ICCV 97306). Generally, grain yield of these commercial lines increased to over 1500 kg/ha when supplemental irrigation was applied. Since there was an accumulation

Table 3. Means of yield and yield traits under rainfed and supplemental irrigated conditions in Marigat in the 2014 seasons.

Genotype	Days to flowering		Days to Maturity		Biomass (kg/ha)		Canopy spread (cm)	
	IRR	RF	IRR	RF	IRR	RF	IRR	RF
ICCV 00108	57	47	98	87	3071	2397	61.33	55.60
ICC 4958	46	40	88	81	2587	2278	60.02	56.31
ICCV 97105	48	42	89	80	2316	1792	53.27	51.22
ICC 1882	63	53	106	99	2280	1603	55.05	44.38
ICCV 92944	53	47	87	79	2511	1908	47.30	43.80
CAVIR	61	53	101	97	2362	1756	52.30	37.40
Ngara local	62	45	99	91	1702	1247	45.31	40.32
ICCV 92318	67	47	98	90	3003	2028	59.20	57.30
ICC 3325	66	52	110	101	2095	1825	47.36	32.83
ICCV 97306	59	48	98	87	2137	1750	53.10	41.80
ICC 283	67	53	87	83	4004	3403	43.32	41.05
Mean	59	48	96	88	2551.6	1998.1	52.50	45.60
CV%	11.2	7.3	9.2	7.8	24.1	17.1	9.2	6.6
P<0.05G	*	**	*	*	**	*	*	*
I.s.d. _{0.05} WR	*		**		**		*	
I.s.d. _{0.05} WR×G	*		*		**		*	

Genotype	Plant height (cm)		100-seed weight (g)		Grain yield (kg/ha)		Harvest index	
	IRR	RF	IRR	RF	IRR	RF	IRR	RF
ICCV 00108	61.50	50.79	24.10	18.41	1561	794	0.51	0.33
ICC 4958	50.60	44.98	24.98	21.11	1295	821	0.50	0.36
ICCV 97105	57.40	42.25	21.27	18.03	1656	997	0.72	0.56
ICC 1882	48.10	39.10	15.70	11.01	901	505	0.40	0.32
ICCV 92944	61.70	43.15	23.86	19.18	1720	991	0.68	0.52
CAVIR	64.80	52.10	31.89	26.04	1390	887	0.59	0.51
Ngara local	50.17	45.05	17.80	14.01	987	669	0.58	0.54
ICCV 92318	61.10	53.03	33.61	27.50	1671	992	0.56	0.49
ICC 3325	47.30	37.13	13.44	9.01	1067	769	0.51	0.42
ICCV 97306	56.19	44.85	31.71	25.19	1505	1001	0.70	0.57
ICC 283	49.01	35.08	16.65	11.09	1080	809	0.27	0.24
Mean	55.3	44.3	23.18	18.23	1348.5	839.6	0.55	0.44
CV%	11.2	13.3	8.9	6.4	7.8	17.4	4.3	5.2
P<0.05G	*	*	*	**	**	**	*	*
I.s.d. _{0.05} WR	*		*		**		*	
I.s.d. _{0.05} WR×G	*		*		**		ns	

G-Genotype, WR-water regime; WR×G-Genotype × water regime interaction, *, **, ***p<0.1, 0.05 and 0.001 significance levels, respectively.

of both grain yield and above ground biomass, the harvest index (HI) also increased by 25% under supplemental irrigation from an average of 0.44 to 0.55 (Table 3). The HI under rainfed condition ranged from 0.24 to 0.54, while under supplemental irrigation ranged from 0.27 to 0.72.

Effects of irrigation (water) regimes on drought tolerance indices (DTI)

Various stress indices of the different genotypes were

extrapolated and there was a significant differences. Mean yield of each genotype under supplemental irrigation (Y_p) (non-stressed conditions) was compared with mean yield of each cultivar under rainfed (Y_s) (stressed) conditions (Table 4). The results showed that all the studied genotypes produced less grain yield under rainfed conditions than when additional water was supplied through supplemental irrigation where grain yield was increased by about 60.3% (mean of 839.5 to 1348.5 kg ha⁻¹) as compared to under non-supplemental irrigation or rainfed conditions.

The results showed that DSSI ranged from 0.66 (ICC

Table 4. Determining grain yield losses using drought tolerance selection indices.

Genotype	Y _p	Y _s	(\bar{Y}_p)	(\bar{Y}_s)	% YD loss	MP	TOL	STI	DSSI	SI	GMP
ICCV 00108	1561	794	839.6	1348.5	96.6	1178	767	0.509	1.03	0.38	1239434
ICC 4958	1295	821	839.6	1348.5	47.7	1058	474	0.634	0.92	0.38	1063195
ICCV 97105	1428	997	839.6	1348.5	43.2	1213	431	0.698	0.80	0.38	1423716
ICC 1882	901	505	839.6	1348.5	78.4	703	396	0.560	1.16	0.38	455005
ICCV 92944	1720	991	839.6	1348.5	73.6	1356	729	0.576	1.02	0.38	1704520
CAVIR	1390	887	839.6	1348.5	56.7	1139	503	0.638	0.96	0.38	1232930
Ngara local	987	669	839.6	1348.5	47.5	828	318	0.678	0.85	0.38	660303
ICCV 92318	1671	992	839.6	1348.5	68.4	1332	679	0.594	1.08	0.38	1657632
ICC 3325	1067	769	839.6	1348.5	38.8	918	298	0.721	0.74	0.38	820523
ICCV 97306	1505	1001	839.6	1348.5	50.3	1253	504	0.665	0.89	0.38	1506505
ICC 283	1080	809	839.6	1348.5	33.5	944.5	271	0.749	0.66	0.38	873720
Mean	1349	840	839.6	1349	60.6	1094	509	0.623	0.62	0.38	1132201

Commerc-Commercial, Var=Variety, Sucep=Susceptible, % YD=percent yield loss, land=Landrace= mean yield of each cultivars under supplemental irrigation (non-stressed), Y_s= mean yield of each cultivar under rainfed (stressed), \bar{Y}_p = mean yield of all cultivars under irrigated (non-stressed), \bar{Y}_s = mean yield of all cultivars under rainfed (stressed), MP= Mean productivity, TOL= Tolerance index, DSSI=Drought Stress susceptibility index, SI=Stress intensity, MP=Mean productivity, TOL=Tolerance index, STI= Stress tolerance index, GMP=Geometric mean productivity.

283) to 1.16 (ICC 1882). Drought tolerant genotypes (ICC 4958, ICCV 97105, ICCV 97306, CAVIR, Ngara local) had a DSSI of <1, lower TOL and STI (Table 5). Similarly, genotypes ICCV 00108, ICCV 92944, Cavir and ICCV 92318 had DSSI almost equal to 1, ranging between 0.96 and 1.08 (Table 5). They also had highest MP amongst all genotypes (1139-1356 kg ha⁻¹), moderate to high TOL (679-767) and moderate STI of 0.509-0.594 (Table 5), indicating moderate tolerance to drought stress.

In contrast, drought susceptible genotypes (ICC 1882) had a high DSSI (of 1.16), low MP (703 kg ha⁻¹) and STI of 0.56 (Table 5). The lowest DSSI was recorded on genotype ICC 283 followed by ICC 3325, ICCV 97105 and Ngara local (DSSI range 0.66-0.83) (Table 5).

The findings showed that drought stress reduced grain yield for most genotypes, but the genetic materials reacted differently to the stress. The grain yield of a number of genotypes like ICCV 00108, ICC 1882, ICCV 92944, and ICCV 92318 was reduced by more than 60% while that of, Cavir and ICCV 97306 was reduced by more than 50% while that of ICCV 97105, ICC 4958, Ngara local was reduced by more than 40% (Table 5). Genotypes ICC 283 and ICC 3325 were least affected. The results showed that larger grain yield reductions (73-96%) were mostly recorded in high yielding genotypes (ICCV 00108, ICCV 92944, and ICCV 92318) under well-watered conditions as compared to under stress conditions (Table 5) In general, genotypes with high performance under normal conditions yielded poorly under stress conditions. Low grain yielding genotypes (e.g Ngara local, ICC 283, ICC 3325) except susceptible genotype ICC 1882, were not severely affected by the yield reduction, ranging from 33-47.5%) (Table 5).

From the findings of this study, genotypes that combined lower tolerance index (STI), lower tolerance

index (TOL) (greater values indicate larger yield reduction and higher drought sensitivity of the genotype) and drought stress susceptibility index (DSSI) (<1 or equal to 1) and higher mean productivity (MP) were drought tolerant. Examples of these genotypes are ICC 4859, Ngara local, ICC 3325 and ICC 283 which had lowest STI, TOL and DSSI values (Table 5). In contrast, genotypes that combined higher drought stress susceptibility index (>1), lower mean productivity and stress tolerance index (STI) were drought susceptible. Such genotypes included ICCV 00108, ICC 1882 and ICCV 92318 (Table 5). The only exception is genotype ICC 1882, which had lowest TOL, indicating that it generally produces low yield under stress. Generally, the tolerance index (TOL) varied among the test genotypes and it ranged from 271 (ICC 283) to 679 (ICCV 92318). Among the commercial lines, ICCV 00108 (767) and ICCV 92944 (729) had higher TOL compared to both the tolerant genotype ICC 4958 (474) and the susceptible genotype ICC 1882 (396). ICCV 92318 (679) had the highest TOL among the tested advance line followed by ICCV 97306 (504) then ICC 3325 (298). Similarly, stress tolerance index (STI) varied among the test genotypes and it ranged from 0.51 (ICCV 00108) to 0.75 (ICC 283) (Table 5).

Mean productivity (MP) varied among the test genotypes (Table 5) and it ranged from 703 (ICC 1882) to 1356 (ICCV 92944) (Table 5). The susceptible genotypes had the lowest MP. while commercial genotypes (ICCV 00108, ICCV 97105, ICCV 92944) and advanced lines (ICCV 92318, and ICCV 97306) had higher MP (1178 to 1332 kg ha⁻¹) as compared to the tolerant genotype ICC 4958 (1058) and the moderately tolerant genotype ICC 283 (944.5). In contrast to other values lower values of SSI and TOL are desirable whereas higher values of MP,

Table 5. Determining grain yield losses using drought tolerance selection indices

Genotype	Type of variety	Yp	Ys	(\bar{Y}_p)	(\bar{Y}_s)	% YD loss	MP	TOL	STI	DSSI	SI	GMP
ICCV 00108	Commerc var	1561	794	839.6	1348.5	96.6	1178	767	0.509	1.03	0.38	1239434
ICC 4958	Tolerant var	1295	821	839.6	1348.5	47.7	1058	474	0.634	0.92	0.38	1063195
ICCV 97105	Commerc var	1428	997	839.6	1348.5	43.2	1213	431	0.698	0.80	0.38	1423716
ICC 1882	Suscep var	901	505	839.6	1348.5	78.4	703	396	0.560	1.16	0.38	455005
ICCV 92944	Commer var	1720	991	839.6	1348.5	73.6	1356	729	0.576	1.02	0.38	1704520
CAVIR	Spanish var	1390	887	839.6	1348.5	56.7	1139	503	0.638	0.96	0.38	1232930
Ngara local	Local land	987	669	839.6	1348.5	47.5	828	318	0.678	0.85	0.38	660303
ICCV 92318	Advance line	1671	992	839.6	1348.5	68.4	1332	679	0.594	1.08	0.38	1657632
ICC 3325	Advance line	1067	769	839.6	1348.5	38.8	918	298	0.721	0.74	0.38	820523
ICCV 97306	Advance line	1505	1001	839.6	1348.5	50.3	1253	504	0.665	0.89	0.38	1506505
ICC 283	Moderately Tolerant line	1080	809	839.6	1348.5	33.5	944.5	271	0.749	0.66	0.38	873720
Mean		1349	840	839.6	1349	60.6	1094	509	0.623	0.62	0.38	1132201

Key: Commerc=Commercial, Var=Variety, Sucep=Susceptible, % YD=percent yield loss, land=Landrace= mean yield of each cultivars under supplemental irrigation (non-stressed), Ys= mean yield of each cultivar under rainfed (stressed), \bar{Y}_p = mean yield of all cultivars under irrigated (non-stressed), \bar{Y}_s = mean yield of all cultivars under rainfed (stressed), MP= Mean productivity, TOL= Tolerance index, DSSI=Drought Stress susceptibility index, SI=Stress intensity, MP=Mean productivity, TOL=Tolerance index, STI= Stress tolerance index, GMP=Geometric mean productivity

GMP and STI are desirable. Overall, genotypes which were moderately tolerant and had high MP values and moderate STI, TOL and DSSI values were ICCV 97105, ICCV 92944, ICCV 97306 and Cavar (Table 5). Commercial varieties like ICCV 00108, ICCV2944 and ICCV 92318 had larger values of TOL than most susceptible genotypes ranging from 767, 729 and 67, respectively indicating that they had higher yield reduction under stress. Tolerant genotypes ICC 283, ICC 3325, ICC 4958, ICCV 7105 and Ngara local had desirable higher values (0.634-0.749) of STI (Table 5).

From the results presented, the intensity of drought measured by the stress intensity (SI) was 0.38 (38%) which is between the interval of 25% to 50%, indicating that the stress intensity applied to this experiment was considered as moderate in Marigat during the study period (Table 5). Geometric mean productivity (GMP) which gives

indication of severity of yield loss under variable fields over season and years varied among the test genotypes (Table 5). It ranged from 455,005 (ICC 1882) to 1,704,520 (ICCV 92944). Commercial genotypes ICCV 00108 (1,239,434), ICCV 97105 (1,423,716), ICCV 92944 (1,704,520), Spanish variety CAVIR (1,232,930), advanced lines ICCV 92318 (1,657,632) and ICCV 97306 (1,506,505) had higher value of GMP compared to the tolerant genotype ICC 4958 (1,063,195) and the moderately tolerant genotype ICC 283 (873,720) (Table 5).

Drought stress reduced grain yield but the genetic materials reacted differently to the stress under both stress and non-stress conditions. The grain yield of a number of genotypes like ICCV 00108, ICC 19882, and ICCV 92944, was reduced by more than 73 to 96% while that of Ngara local, ICC 3325 and ICC 283 and was not affected much with yield reduction of 30 to 47%

(Table 5). Larger grain yield reductions were mostly recorded in high yielding genotypes under stress conditions as compared to under supplemental irrigation (Table 5). In general, genotypes with high performance under normal conditions yielded poorly under stress conditions. Low grain yielding genotypes were not severely affected by the yield reduction (Table 5). Genotypes that combined lower tolerance index and stress susceptibility index and higher mean productivity and stress tolerance index were drought tolerant. Examples of these genotypes are ICCV 92944, ICCV 92318 and ICCV 97306 (Table 5).

Correlation analysis of yield and yield traits

The results of correlation analysis of yield, and yield components and between yield and drought

Table 6. Correlation analysis of chickpea genotypes for measured traits evaluated under rainfed supplemental irrigation (non-stress) conditions.

Correlation	100 seed weight	Harvest Index	Canopy spread	Plant height	Biomass	Pods per plant	Seeds per pod
Harvest Index	0.011						
Canopy spread	0.791*	-0.146					
Plant height	0.724**	0.114	0.752**				
Biomass	0.201	-0.422*	0.231	-0.027			
Pods per plant	0.564*	0.345*	0.231	0.323*	0.451*		
Seeds per pod	0.455*	0.365*	0.291	0.392*	0.761**	0.785***	
Seed yield /plot	0.239	0.721**	0.105	0.178	0.267*	0.567**	0.761**

* and **Significant at 0.05 and 0.01 probability level, respectively.

Table 7. Correlation coefficients of chickpea genotypes of measured under rainfed (stress) conditions.

Correlation	100 seed weight	Harvest Index	Canopy Spread	Plant Height	Biomass	Pods per plant	Seeds per pod
Harvest index	-0.053						
Canopy spread	0.438*	-0.081					
Plant height	0.626**	0.003	0.455**				
Biomass	0.106	-0.152	0.272	-0.161			
Pods per plant	0.463*	0.425*	0.211	0.213	0.439*		
Seeds per pod	0.425*	0.325*	0.231	0.292	0.451*	0.675**	
Seed yield/plot	0.073	0.737*	0.167	-0.071	0.525**	0.512**	0.678**

* and **Significant at 0.05 and 0.01 probability level, respectively.

tolerance indices of the mean yield under both rainfed (water stress) and irrigated (non-stress) are presented in Tables 6, 7 and 8. Under both conditions, there were positive relationships between yield and yield components, yield and tolerance indices and also amongst yield components and indices individually (Tables 6, 7, and 8).

Correlation coefficient analysis for seed yield per plot and its components under irrigated conditions indicated that out of seven characters, seed yield per plot had significant and positive correlation with 100-seed weight, canopy spread, harvest index, biomass (biomass) per plant, the number of pods per plant, the number of seeds per plant (Tables 6 and 7). Also positive and significant relationships were found statistically between the HI and seed yield per plot, between the number seed yield per plot and biomass, between HI and biomass and plant height, between the number of seeds per plant and the number of pods per plant and the number of seeds per pods, between the number of pods per plant and the number of seeds per pod, between the number of seeds per pod and HI, 100 seed weight, plant height and biomass (Tables 6 and 7). Also number of pods per plant was positively and significantly correlated with between 100 seed weight, the number of seeds per plant and

plant height (Tables 6 and 7). There was however no significant relationships recorded under stress conditions for seed yield per plot and 100 seed weight and plant height. Negative and significant relationships were determined statistically between the biomass and HI canopy spread in both conditions (Tables 6 and 7).

Correlation analysis of drought tolerance indices of test chickpea genotypes

The results of correlation analysis of yield and drought tolerance indices under both rainfed (water stress) and irrigated (non-stress) are presented in Table 8. The results of correlation analysis among various tolerance drought indices showed positive and significant correlation between yield and most of the measured drought indices in well watered condition (Y_p) (non-stress), except TOL and STI. Also, the correlation among drought tolerance quantitative indices and stressed and non-stressed yield indicated that stress tolerance index (STI) was correlated with stressed (Y_s) and non-stressed (Y_p) yield, mean productivity (MP) and geometric mean productivity (GMP).

However under stress conditions (Y_s), Y_p was only

Table 8. Correlation analysis of drought tolerance indices of the mean yield of chickpea genotypes evaluated under rainfed (stress) and supplemental irrigation (non-stress) conditions.

Correlation	Yp	Ys	MP	GMP	TOL	DSSI
Ys	0.567**					
MP	0.874**	0.561*				
GMP	0.917**	0.689**	0.891**			
TOL	0.476	0.516	0.751**	0.761**		
DSSI	0.789**	0.434*	0.345	0.344	0.789**	
STI	0.481	0.789**	0.856**	0.784**	0.678**	0.412

* and **Non significant and significant at 0.05 and 0.01 probability level, respectively.

significant with MP, GMP and STI (Table 8). Similarly, there was no significant correlation found between TOL and DSSI with yield in both conditions (Table 8). The significant and positive correlation for Yp and MP, GMP and STI showed that these indices were more effective in identifying high yielding cultivars under different moisture conditions (Table 8). DSSI was significantly and positively correlated with Ys and TOL indicating that it may be a useful indicator when the stress is severe as compared to MP, GMP and STI which were significant under less severe stress conditions, indication that they could be useful indicators when the stress is less severe (Table 8).

DISCUSSION

Genetic variability is essential for the establishment of breeding programme in crop. In this study, genotypes tested reacted differently to water stress indicating the existence of genetic variability for drought tolerance amongst the eleven varied tested chickpea parental germplasm, indicating that improvement can be achieved using such germplasm. The significant G × E interaction ($P < 0.05$) showed high level of genotypic difference in chickpea genotypes and all studied traits.

In the yield performance evaluation, high yielding genotypes like ICCV 00108, ICCV 97105, ICCV 92944 and ICCV 92318 produced almost 60% more than low yielding genotypes in non-stressed conditions. However, it should be noted that under stressed conditions, some low yielding remained stable across environment while some high yielding genotypes that yielded low. Thus, from the test genotypes, four groups were generated:

Group A - High yielding and drought tolerant (yield was not significantly reduced by drought; ICCV 97105, ICC 4958, Cavir, and ICCV 97306).

Group B - High yielding and drought susceptible genotypes (yield was highly reduced by drought; ICCV 00108, ICCV 92944, ICCV 92318).

Group C - Low yielding and drought tolerant (yield not reduced; ICC 238, ICC 3325, Ngara local)

Group D - Low yielding and drought susceptible genotypes (ICC 1882).

From the study, there was an increase grain yield by about 60.3% (means of 839.5 to 1348.5 kg/ha) when supplemental irrigation was introduced at reproductive stage of growth. This increase can be attributed to the fact that there was a reduction of moisture stress during the most growth sensitive stage under irrigated condition as compared to rainfed conditions. This could have guarded against yield loss associated with flower abortions, reductions in pods per plant and seeds per pod. Similar findings were reported by Chiulele (2010) and Turk et al. (1980) in cowpea who indicated that the reduction in grain yield in grain yield of cowpea was a result of reduction in number of pods per plant and seed weight due to detrimental effects of drought on pod set and grain filling. Similarly, Bahar and Yildirim (2010) indicated that plants are most prone to damage due to limited water during flowering and pod setting stages in wheat. In addition, supplemental irrigation during the flowering and podding stage could have reduced the effects yield reduction, possibly from physiological interference beyond osmotic adjustment as a result of rapid increment in drought stress and temperature as the season advanced.

Furthermore, a study by Zhang et al. (2000) supplemental irrigation plays a major role in boosting and stabilizing the productivity in winter-sown chickpea in Italy. Similarly, Samarah et al. (2004) and Reddy et al. (2004) noted that drought is detrimental for plant growth, yield and mineral nutrition and is one of crop growth limitation of chickpea production in varied agro-ecologies. Thus, the commonest strategy for reducing G × E interaction involves selecting genotypes with better stability across a wide range of environments (water stress and non-stress conditions) in order to better predict their behaviour (Farshadfar et al., 2011).

Some traits like 100-seed weight was less affected by drought than other traits and most of the genotypes showed greater no significant variation under stressed conditions under non-stressed conditions. Studies of the trends of these traits in contrasting genotypes showed that out of seven characters, seed yield per plot had significant and positive correlation with 100-seed weight, canopy spread, harvest index, biomass, the number of pods per plant, the number of seeds per plant

were positively correlated, and hence they could easily distinguish genotypes in different drought tolerance groups. Therefore, these traits should be taken into account when selecting genotypes under drought conditions.

The total determining coefficient linking seed yield per plot an seed yield per unit area are 0.673 (67.3%) and 0.428 (42.8%), respectively in the model which were used in our research and also total determining coefficient related to 100 seed weight was 0.696 (69.6%) in the same model. In this study, the various physiological changes observed among the genotypes could have been as a result of moisture deficit on metabolic processes which include photosynthesis, enzymatic activity among others. Meteorological data in cropping period at the experimental site revealed that during the cropping season (Aug-Nov) the temperature ranged between 26 and 29°C with mean of 27.5°C. These shows that the crop was exposed to high temperature regimes which was high temperatures as Mola et al. (2018) noted that the peak photosynthetic rate was observed at 22°C in chickpea, and reduced at 28°C with increasing drought stress. The greatest mean yield reduction (>66%) was recorded among the highest yielding genotypes (ICCV 00108, ICCV 92318, ICCV 97105 and ICCV 92944) and susceptible genotype 1882 (Table 4), indicating genotypic variations to flowering and podding stage drought stress. In contrast Ngara local and tolerant genotypes (ICC 4958) had lower yield reduction (27-36%). This in agreement with findings earlier reported that there is differential genotypic response to drought stress, as a result of variation in physiological parameters in different crops (Reza et al., 2013).

Furthermore, negative effects of moisture stress were experienced in the 100 seed weight (Ouji et al., 2016; Bicer et al., 2004), grain yield and biomass (Nelson, 2001; Romteke et al., 1998; Silim and Saxena, 1993; Singh et al., 1991; Summer-Field and Roberts, 1986). Also, biomass and biomass components such plant height and canopy spread were reduced under moisture stress conditions. This is probably because the plant under moisture stress conditions would invest less to the stem and leaf to reduce the water loss to minimum level (Anwar et al., 2017; Farooq et al., 2012). Furthermore, a study by Mohammadian et al. (2005), noted that there was a decrease in leaf area index, leaf biomass, shoots biomass, and root biomass decreased under moisture stress.

Plants tend to reduce the reproductive investment that requires vast amounts of energy and water. This is due to reduction in photosynthesis and changes in phenology (e.g., shortening growth period and early flowering) in relation to drought response, cause significant reduction in biomass allocation to reproductive parts (Anwar et al., 2017). Thus the reduction of grain yields and yield components experienced in the study. As earlier reported, G × E analysis is important to identify superior varieties

and their adaptation to and stability in diverse agro-ecologies (Kanouni et al., 2015), indicating that amongst high yielding genotype ICCV 97105 was most stable.

The use of drought tolerance quantitative indices revealed possibility of selecting genotypes under diverse environments. Tolerance indices were calculated on the basis of grain yield. For example, correlations indicated that stress tolerance index (STI) was correlated with stressed (Ys) and non-stressed (YP) yield, mean productivity (MP) and geometric mean productivity (GMP). This suggests that selection based on this index would improve both stressed and non-stressed yield for targeted genotypes. Furthermore the results showed that, stress tolerance index (STI) enabled identification and grouping of test genotypes into 4 groups that are high yielding and drought tolerant, high yielding and drought susceptible genotypes, low yielding and drought and lastly group D, low yielding and drought susceptible genotypes. This suggests that this index was the best among tested indices for selecting genotypes for drought tolerance under semi-arid conditions under supplemental irrigation, which included ICCV 00108 and ICCV 92944. In addition, the significant and positive correlation for Yp and MP, GMP and STI, showed that these indices were more effective in identifying high yielding cultivars under low moisture stress conditions (Table 8). For DSSI and TOL, lower values are desirable whereas for MP, GMP and STI, higher values are desirable and the greater the TOL value, the larger yield reduction under drought stress conditions and the higher drought sensitivity (Fernandez, 1992). The greater the DSSI and TOL values, the greater sensitivity of the genotype to stress, thus a smaller value of these indices are usually favoured. The results showed that DSSI was significantly and positively correlated with Ys and TOL, indicating that it may be a useful indicator when the stress is severe as compared to MP, GMP and STI which were significant under less severe stress conditions. In this regard, genotypes ICC 3325, ICC 283 and Ngara local were selected as stable under severe drought stress and compared to check (ICC 4958). This is in agreements with reports by Rosielle and Hamblin (1981) who noted that, selection based on the tolerance index often leads to selecting cultivars which have low yields under non-stress conditions. However this finding contrasts the earlier reports by Farshadfar et al., (2011) on 64 chickpea lines where a selection based on minimum yield reduction under stress conditions in comparison with non-stress conditions, TOL failed to identify the most tolerant genotypes. Stress intensity is mild when yield reduction is between 0 and 25%, moderate when yield reduction is situated between 25 and 50% and severe when yield reduction is between 50 and 100%. The results of this study showed that, the intensity of drought measured by the stress intensity (SI) was 0.38 (38%) which is between the interval of 25 to 50%, indicating that the stress intensity applied to this experiment was considered as moderate in Marigat

during the study period. Therefore, based on this limited sample and environments, testing and selection under non-stress and stress conditions alone may not be the most effective for increasing yield under drought stress. The results of calculated gain from indirect selection in moisture stress environment would improve yield in moisture stress environment better than selection from non-moisture stress environment. Chickpea breeders should, therefore, take into account the stress severity of the environment when choosing an index.

Conclusion

In this study, the effect of moisture stress treatments and their interaction with genotypes were significant for yield and most studied traits. Therefore be concluded that the genotypes responded differently to moisture stress treatments and overall supplemental irrigation reduced grain yield losses by about 60.3% (from mean of 1348.5 to 839.5 kg/ha), being highest among high yielding genotypes. Use of stress tolerance indices enabled identification and grouping of test genotypes into 4 groups with varied responses to yield losses and adaptation to stress and no-stress conditions. The DSSI and TOL are suggested as useful indicators when the stress is less severe while MP, GMP and STI are suggested as useful indicators for selecting the best genotypes where the stress is less severe. Overall these results revealed a wide range of variability for different morphological and physiological traits and strong correlation with yield in both stress and non-stress environmental conditions, suggesting indirect selection for high yield chickpea genotypes would be effective for these traits. Genotypes ICCV 00108, ICCV 92318 and ICCV 92944 are suitable for supplemental irrigation to maintain high potential yield, while ICCV 97105, ICCV 97306 and Cavir could be recommended for production under rainfed conditions. Apart from ICC 4958 which is recommended genotype for drought tolerance screening, Ngara local, ICC 283 and ICC 3325 had high tolerance levels and should be included in drought screening as checks under similar climatic conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Ahmad F, Gaur P, Croser J (2006). Chickpea (*Cicer arietinum* L.) in Genetic Resources, Chromosome Engineering, and Crop Improvement (ed. Ram J. Singh) 229–267. ISBN 9780849336393 (CRC Press: Boca Raton, F. L., Taylor and Francis, London, UK, 2006).
- Anwar E, Yan Z, Di Tian, Han W, Tang Z, Fang J (2017). Drought effect on plant biomass allocation: A meta-analysis. *Ecology and Evolution* 7(24):11002-11010.
- Bahar B, Yildirim M (2010). Heat and drought resistances criteria in spring bread wheat: Drought resistance parameter. *Journal of Scientific Research and Assays* 5(13):1742-1745.
- Bampidis VA, Christodoulou V (2011). Chickpeas (*Cicer arietinum* L.) in animal nutrition: A review. *Animal Feed Science and Technology* 168(1-2):1-20.
- Bicer B, Narin KA, Akar DA, (2004). The effect of irrigation on spring-sown chickpea. *Journal of Agronomy* 3(3):154-158.
- Chiulele RM (2010). Breeding cowpea (*Vigna unguiculata* (L.) walp.) for improved drought tolerance in Mozambique. Doctor of Philosophy, University of KwaZulu-Natal, 2010.
- Drikvand R, Hossainpur T, Ismaili, A, Salahvarzi E (2012). Assessment of drought tolerance indices for screening of rainfed wheat genotypes. *Journal of Food, Agriculture and Environment* 10(1):768-772.
- FAOSTAT (2014). Individual crop country report of 2014. www.fao.org, accessed on 26 January 2015
- Farshadfar E, Mahmodi N, Yaghotipoor A (2011). AMMI stability value and simultaneous estimation of yield and yield stability in bread wheat (*Triticum aestivum* L.). *Australian Journal of Crop Science* 5(13):1837-1844.
- Farshadfar E, Sheibanirad A, Soltanian M (2014). Screening landraces of bread wheat genotypes for drought tolerance in the field and laboratory. *International Journal of Farming and Allied Sciences*, 3(3):304-311.
- Farooq M, Hussain M, Wahid A, Siddique KHM (2012). Drought stress in plants: An overview. In R. Aroca (Ed.), *Plant responses to drought stress: From morphological to molecular features*, 1st edn. (pp. 1-33). Berlin Heidelberg: Springer.
- Fernandez GCJ (1992). Effective selection criteria for assessing stress tolerance. In: Kuo C.G. (Ed.), *Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress*, Publication, Tainan, Taiwan.
- Fischer RA, Maurer R (1978). Drought resistance in spring wheat cultivars: I. Grain yield responses. *Australian Journal of Agriculture Research* 29(5):897-912.
- Gaur PM, Pande S, Sharma HC, Gowda CLL, Sharma KK, Crouch JH, and Vadez V (2007). Genetic Enhancement of Stress Tolerance in Chickpea: Presents Status and Future Prospects." In *Crop Production Stress Environments: Genetic and Management Options*, edited by Singh, D. P., Tomar, V. S., Behl, R. K., Upadhyaya, S. D., Bhale, M. S., Khare, D. Jodhpur, India: AGROBIOS International Publishing pp. 85-94.
- Gaur PM (2013). Climate change and heat stress tolerance in chickpea in *Climate Change and Plant Abiotic Stress Tolerance* (eds N. Tuteja and S. S. Gill) pp. 837-856; 10.1002/9783527675265.ch31 (Wiley-VCH Verlag GmbH & Co. 2013).
- Gavuzzi P, Rizza F, Palumbo M, Campalino RG, Ricciardi GL, Borghi B, (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journal of Plant Science* 77(4):523-531.
- Golbashy M, Ebrahimi M, Khavari Khorasani S, Choukan R (2010). Evaluation of drought tolerance of some corn (*Zea mays* L.) hybrids in Iran. *African Journal of Agricultural Research* 5(19):2714-2719.
- ICRISAT (2012). <http://www.icrisat.org> accessed on the 19th March 2015 ICRISAT annual reports of 1989, 2009 and 2013. <http://www.fao.org> accessed on the 5 June 2015 FAO Country report 2012.
- Jaetzold R, Schmidt H (1983). *Farm management handbook of Kenya*, volume II: natural conditions and farm management information. Part a: West Kenya; part b: Central Kenya; part c: East Kenya, Nairobi: Ministry of Agriculture.
- KARI (2009). Kenya Agricultural Research Institute strategic plan 2009-2014. KARI, Nairobi, Kenya. www.kari.org/?q=content/perkerra-background Accessed on the 19th March 2012.
- Kanouni H, Farayedi Y, Saeid A, Sabaghpour SH (2015). Stability Analyses for Seed Yield of Chickpea (*Cicer arietinum* L.) Genotypes in the Western Cold Zone of Iran. *Journal of Agricultural Science* 7(5):219.
- Kumar J, Abbo S (2001). Genetics of flowering time in chickpea and its bearing on productivity in semiarid environments. *Advances in Agronomy* 72:107-138.
- Kimurto PK, Towett BK, Mulwa RK, Cheruiyot EK, Gangarao R, Silim S,

- Varshney RK (2009). Screening for drought tolerance in selected chickpea (*Cicer arietinum* L.) germplasm in semi-arid areas of Kenya. Proceedings of annual research meetings of CGIAR generation challenge program chickpea annual research meeting, 20th-23rd September 2009. Bamako, Mali.
- Kimurto PK, Towett BK, Njogu N, Jeptanui L, Gangarao NVPR, Silim S, Kaloki PK, Korir PK, Macharia JK (2013). Evaluation of chickpea genotypes for tolerance to ascochyta blight (*Ascochyta rabiei*) disease in the dry highlands of Kenya. *Journal of phytopathologia Mediterranean* 52:611-613.
- Liu JP, Song M, Horton RM, Hu Y (2013). Reducing spread in climate model projections of a September ice-free Arctic. Proceedings of the National Academy of Science 110:12571-12576, doi:10.1073/pnas.1219716110.
- Ludlow MM, Muchow RC (1990). A Critical Evaluation of Traits for Improving Crop Yields in Water-Limited Environments. *Advances in Agronomy* 43:107-153.
- Mallu TS, Nyende AB, Ganga Rao NVPR, Odeny DA, Mwangi SG (2015). Assessment of interrelationship among agronomic and yield characters of chickpea. *International Journal of Agriculture and Crop Sciences* 8(2):128-135.
- Malik SR, Bakhsh A, Ahsan MA., Iqbal U, Iqbal SM (2009). Assessment of genetic variability and interrelationship among some agronomic traits in chickpea. *International Journal of Agriculture and Biology* 12(1):1814-9596.
- Malik S, Bakhsh A, Asif MA, Iqbal U, Iqbal SM (2010). Assessment of genetic variability and interrelationship among some agronomic traits in chickpea. *International Journal of Agriculture and Biology* 12:81-85.
- Mola T, Alemayehu S, Asnake F, Ojiewo C, Alemu K, Degefu T (2018). Heat Tolerance Responses of Chickpea Genotypes in the Thermal Zone of Ethiopia, a Case of Werer Station. *Ethiopian Journal of Crop Science* 6(2).
- Mohammadian R, Moghaddam M, Rahimian H, Sadeghian SY (2005). Effect of early season drought stress on growth characteristics of sugar beet genotypes. *Turkish Journal of Agriculture and Forestry* 29:357-368.
- Mitra J (2001). Genetics and genetic improvement of drought resistance in crop plants. *Current Science* 80(6):758-762.
- Nelson RM (2001). Water relations of forest fuels. In 'Forest fires: Behavior and Ecological Effects. Eds EA Johnson, K Miyanishi pp. 79-149.
- Ondiek JO, Ogore PB, Shakala EK, Kaburu GM (2013). Feed intake, digestibility and performance of growing small East African goats offered maize (*Zea mays*) stover supplemented with *Balanitesaegyptiaca* and *Acacia tortilis* leaf forages. *Basic Research Journal of Agricultural Science and Review* 2(1):21-26.
- Ouji A, El-Bok S, Mouelhi M, Ben Younes M, Kharrat M (2016). Yield and Yield Components of Chickpea (*Cicer arietinum* L.) as Influenced by Supplemental Irrigation under Semi-arid Region of Tunisia. *World Journal of Agricultural Research* 4(5):153-157. doi: 10.12691/wjar-4-5-5
- Ramakrishna A, Reddy SLN (1993). Production potential and economic feasibility of different crop sequences in rice (*Oryza sativa*) fallows. *Indian Journal of Agricultural Sciences* 63(10):611-615
- Ramirez-Vallejo P, Kelly JD (1998). Traits related to drought resistance in common bean. *Euphytica* 99(2):127-136.
- Ravi N, Sharma HM, Singh RP, Nandan R (1998). Response of late-sown chickpea to irrigation and foliar nutrition in calcareous soil. *Journal of Applied Biology* 8:5-8.
- Reddy NN, Ahlawat IS (1998). Response of chickpea (*Cicer arietinum*) genotypes to irrigation and fertilizers under late-sown conditions. *Indian Journal of Agronomy* 43(1):95-101.
- Reddy AR, Chaitanya KV, Vivekanandan M (2004). Drought induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of Plant Physiology* 161:1189-1202.
- Romteke SD, Chetti MB, Salimath M (1998). Seasonal variation in yield and yield components in gram (*cicerarietinum* L.). *Indian Journal of Agriculture and Science* 68:251-254.
- Rosielle AA, Hamblin J (1981). Theoretical aspects of selection for yield in stress and non-stress environment. *Crop Science* 21(6):943-946.
- Samarah N, Mullen R, Cianzio S (2004). Size distribution and mineral nutrients of soybean seeds in response to drought stress. *Journal of Plant Nutrition* 27(5):815-835.
- Schneider KA, Rosales-Serna R, Ibarra-Perez F, Cazares-Enriquez B, Acosta-Gallegos JA, Ramirez-Vallejo P, Wassimi N, Kelly JD (1997). Improving common bean performance under drought stress. *Crop Science* 37(1):43-50.
- Turk KJ, Hall AE, Asbell CW (1980). Drought adaptation of cowpea. I. Influence of drought on seed yield. *Agronomy Journal* 72(3):413-420.
- Saxena NP (2003). Management of Drought In Chickpea-Holistic Approach. In: Saxena NP (Eds) Management of Agricultural Drought-Agronomic And Genetic Options. Oxford And IBH Publishing Co.Pvt Ltd. New Delhi, India pp. 103-122.
- Singh N, Luthra R, Sangwan RS (1991). Mobilization of starch and essential oil biogenesis during leaf ontogeny of lemongrass (*Cymbopogon flexuosus*). *Plant Cell Physiology* 32(6):803-811.
- Silim SN, Saxena MC (1993). Adaptation of spring sown chickpea to Mediterranean basin. II. Factors influencing drought. *Field Crop Research* 34(2):137-146.
- Soltani A, Khoie FR, Ghasseni-Golezani K, Moghaddam M (2000). A simulation study of chickpea crop to limited irrigation in a semi-arid environment. *Journal of Agricultural Water Management* 49(3):225-237.
- Summer-Field RT, Roberts EH (1986). Grain legume crops, Mackays of Chatham. Kent, London, 1986.
- Turner NC, Wright GC, Siddique KHM (2001). Adaptation of grain legumes (pulses) to water – limited environments. *Advances in Agronomy* 71:193-231.
- Silim S, Saxena M (1993). Adaptation of spring-sown chickpea to the Mediterranean basin: I response to moisture supply. *Field Crops Research* 34(2):121-136.
- Sio-Se MA, Ahmadi A, Postini K, Mohammadi V (2006). Evaluation of drought resistance indices under various environmental conditions. *Field Crops Research* 98(2-3):222-229.
- Zhang Y, Bell A, Perlman P, Leibowitz M (2000). Pentamidine inhibits mitochondrial intron splicing and translation in *Saccharomyces cerevisiae*. *RNA* 6(7):937-951.