Genotype by Environment Interaction and Stability of Chickpea (*Cicer arietinum* (L.)) Genotypes in Southern Ethiopia

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Abstract

The production of chickpea in Ethiopia is being pushed into less favorable areas adjacent to and in the southern rift valley where it is exposed to severe moisture stress during the post-rainy growing season. Fifteen chickpea genotypes consisting of seven released varieties, six kabuli advanced lines obtained from ICARDA and two local checks, were tested in three replications of RCBD at three locations during 2012 and 2013 (six environments, E1 to E6) in southern Ethiopia. The objectives of the study were to determine the difference in grain yield between the genotypes and between the environments and investigate the magnitude and nature of G x E interaction, assess the stability of the chickpea genotypes and identify those with wide or narrow adaptation. Due to heterogeneity of errors over the six environments a transformation (Geometric mean x Log (Yield in Kg ha^{-1}) was used. The Environment main effect and the GxE interaction were highly significant. Grain yield ranged between 31.8 and 68.7 units (0.66 and 5.2 tons ha^{-1}) at E1 and E2, respectively; a reduction of 53.6% (87.3% in the original units, Kg ha^{-1}) due to moisture stress. Univariate stability parameters identified four high yielding and stable genotypes, Ejeri, Mastewal, Wolayita Local and Habru for wide adaptation. There was no correlation between yield and stability; simultaneous selection for both high yield and stability is possible. Both AMMI and GGE put the lowest yielding environment, E1 as a distinct environment. Yield at E1 was negatively correlated with yield at other environments. AMMI and GGE identified the same four genotypes selected by W_i, (S^2d_i), and ASV_i for wide adaptation (Group I). Arerti, Butajira local, Cheffe and Naatolii (Group II) were adapted to high yielding environments similar to JolleAndegna (Butajira) and Taba in Wolayita. Shasho, FLIP03-28C and FLIP07-81C (Group III) were adapted to low yielding environments such as Halaba (Huletegna Choroko). Compared to Group II, genotypes in Group III had the highest mean yield under stress (E1) (8.8 vs 5.1), geometric mean yield (20.6 vs 17.4), Yield Stability Index (0.18 vs 0.08), Drought Resistance Index (0.24 vs 0.07), and the lowest percent yield reduction (81.7 vs 91.9%) and Drought Susceptibility Index (0.79 vs 0.91).

Keywords: AMMI, drought index, GGE, stability
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INTRODUCTION

Chickpea [*Cicer arietinum* (L.)] is an important food legume of the semi-arid tropics and the warm temperate zones (Onwueme and Sinha, 1991). The crop is considered as one of the most important legumes used as food and feed and is cultivated on over 13.5 million hectares in a wide range of environments across the world (FAOSTAT, 2013). Ethiopia ranks 7th after India, Australia, Pakistan, Turkey, Myanmar, and the Islamic Republic of Iran in area and production of chickpea (FAOSTAT, 2013). With an area of 239,751 ha and annual production 4,586,823 quintals, it ranks 3rd among pulses after faba beans and haricot beans (CSA, 2014/15). On the highlands of Ethiopia, where it is rotated with tef and wheat to enhance soil fertility, chickpea is produced on residual moisture after the end of the main rains from August to December and faces relatively less moisture stress due to the high water holding capacity of the vertisols and the cool growing season (Geletu Bejiga and Ketema Daba, 2003).

Chickpea production is being extended to non-traditional agro-ecologies of the rift valley in southern Ethiopia, where the crop is exposed to a more severe moisture stress during the post-rainy season. The climatic variations between different locations (predictable variation) and the variation within the same location over different years (the unpredictable variation) are higher here than in the highlands. The same location may get rainfall as high as in the highlands and high yields comparable to that in the potential highlands can be obtained in few years, while in most of the years rainfall is so low, its distribution so irregular that hardly any harvest can be expected. Selection for yield under moisture stress is generally considered less efficient than selection for yield under well-watered conditions (Rosielle and Hamblin, 1981). Stability of yield is as important as, or even more important than, high mean yield of a variety to be released for such areas. Baker and Léon (1988) defined GxE interaction as the failure of genotypes to achieve the same relative performance in different environments. Thus, a stable genotype can be referred to as the one that is capable of utilizing the resources available in high yielding environments and has a mean performance that is above average in all environments (Eberhart and Russell, 1966). Knowledge of the magnitude and pattern of GxE interactions and stability analysis are important for understanding the response of different genotypes to varying environments and for identification of stable and widely adapted and unstable but specifically adapted genotypes.

Using the genetic variability within the Ethiopian chickpea germplasm and introductions from ICARDA and ICRISAT, the chickpea improvement program of Ethiopia has released 11 *desi* and 12 *kabuli* type varieties mainly for the highlands and mid-altitudes of the country (MoARD, 2015). The performance of these varieties under the moisture stress conditions of the southern rift valley has not been studied. There is also limited information on the extent and pattern of GxE interaction and the stability of these released chickpea varieties when they are grown in the southern rift valley. Therefore, the objectives of the present study were to evaluate the performance of the released varieties and potential lines in the southern rift valley, determine the extent to which Environment, Genotype and GxE interaction affect grain yield, study the pattern of the GxE interaction and yield stability of the genotypes and identify genotypes that are widely or specifically adapted.

MATERIALS AND METHODS

Description of the experimental sites

The experiments were conducted at three locations in the southern rift valley of Ethiopia, Jolle Andegna, Taba and Huletegna Choroko during 2012 and 2013 (Table 1).

Experimental materials

Fifteen chickpea genotypes (seven released varieties, six elite lines and two land races) were used for the study. The released varieties were obtained from Agronomy section of the School of Plant and Horticultural Sciences, Hawassa University, College of Agriculture, which initially were from Debre Zeit Agricultural Research Center.

The advanced lines were extra-early maturing genotypes obtained from ICARDA in 2011 and have been tested for one year (September, 2011-February, 2012). The local materials were obtained from farmers of Jolle Andegna and Taba vicinity. The description of the genotypes is provided in Table 2.

Table 1. Description of the experiment sites

Location	Altitude (masl*)	Annual RF (mm)	Mean annual Temp (^oC)	Soil texture	Zone
Jolle Andegna	1923	922	18.4	Silty clay loam	Gurage
Taba	1915	989	18.7	Silty loam	Wolayita
Huletegna Choroko	1807	774	20.6	Clay loam	Halaba

* masl = meters above sea level

Source: (NMA, 2013) and College of Agriculture, Hawassa University, Soil Laboratory.

Design of the experiment and trial management

The randomized complete block design (RCBD) with three replications was used to conduct the experiments. Plot size was 11.2 m^2 consisting of eight rows, each 3.5 m long. The inter- and intra-row spacing was 40 and 10 cm, respectively.Diammonium Phosphate (DAP) (18:46:0 N:P:K) at the rate of 60 kg ha^{-1} was uniformly applied at planting followed by Zinc fertilizer ($ZnSO_4.7H_2O$) at 25 kg ha^{-1} drilled in rows and incorporated with the soil before planting. The experiments were planted at different dates based on rainfall pattern and soil moisture content across the locations over the years. At Huletegna Choroko the experiment was planted on September 8 in 2012 and August 23 in 2013. At Jolle Andegna, planting was done on September 20 in 2012 and September 4 in 2013, while at Taba planting was done on September 14 in 2012 and September 17 in 2013.

Data collection

The middle six rows of each plot were used for collecting data on phenology (days to flowering and maturity), growth parameters (number of primary and secondary branches, plant height) and seed yield and its components (number of pods per plant, seeds per pod, thousand seed weight, biomass and seed yield, harvest index). In this paper only seed yield was analyzed.

Data analysis

Each location-year combination was considered as a separate environment in this study, producing six environments which were considered random. The General Linear Model (GLM) of SAS software (SAS, 2008) was used for ANOVA of data from individual locations and for the combined data. Prior to the combined ANOVA, homogeneity of error variances over the six environments was tested.

Table 2. Description of chickpea genotypes studied at three sites during 2012-2013 in southern Ethiopia

Genotypes	Code	Days to maturity	Type	Line	Year of release
Arerti	a	105-155	Kabuli	FLIP89-84C	1999
Butajira (local)	b		Desi		Landrace
Cheffe	c	93-150	Kabuli	ICCV-92318	2004
Ejeri	d	118-129	Kabuli	FLIP97-263C	2005
Habru	e	91-150	Kabuli	FLIP88-42C	2004
Mastewal	f	98-142	Desi	ICCV-92006	2006
Naatolii	g	88-142	Desi	ICCX-910112-6	2007
Shasho	h	110-125	Kabuli	ICCV-93512	1999
Wolayita (local)	i		Desi		Landrace
FLI P03-53C	j	119*	Kabuli	FLI P03-53C	Adv. Line
FLI P03-102C	k	122*	Kabuli	FLI P03-102C	Adv. Line
FLI P03-128C	l	119*	Kabuli	FLI P03-128C	Adv. Line
FLI P07-81C	m	125*	Kabuli	FLI P07-81C	Adv. Line
FLI P08-60C	n	128*	Kabuli	FLI P08-60C	Adv. Line
FLIP07-27C	o	126*	Kabuli	FLIP07-27C	Adv. Line

Stability analysis was conducted using the SAS program developed by Hussein *et al.*, (2000). Three most popular univariate stability parameters (Wricke's Ecovalence (W_i) (Wricke, 1962), Deviations from regression (S^2d_i) (Eberhart and Russel, 1966), and AMMII Stability Value (ASV) were used. The slopes were used as measures of responsiveness of each genotype to environment. Two multivariate analytical tools, AMMI (Gauch, 1988; Zobel *et al.*, 1988) and (GGE) biplots were also used to shed more light on the significant GxE interaction and determine the stability and adaptability of each genotype. Some indices of drought tolerance which indicate the response of a specific genotype to drought stress, were also used to compare the genotypes. For this, the environment at which the genotypes are exposed to the most severe moisture stress is taken as Stress environment (Xds or Yds) and the environment under which the highest yield is obtained is considered as non-stress environment (Xns or Yns). The Indices used were:

Drought intensity index (DII) was calculated for the whole experiment.

DII = 1-Xds/Xns, where Xds and Xns are the mean seed yield of all genotypes under drought stress and non-stress environment, respectively. The DII is used to compare the stress between two or more experiments. DII of 0.7 and above indicates severe drought stress, while DII of 0.2 - 0.5 indicates mild drought stress (Fischer and Maurer 1978).

Drought Index (DI) = Xds/Xns. This was also calculated for the whole experiment.
Drought susceptibility index (DSI): DSI = [1-(Yds/Yns)/DII] (Fischer and Maurer 1978).
Where Yds and Yns are the mean seed yield of a specific genotype under drought stressed and non-stressed environments, respectively.
Drought resistance index (DRI) = Yds*((YDS/Yns)/Xds) (Fernandez, 1993)
Geometric mean (GM): = $(Yds \times Yns)^{0.5}$, (Fernandez, 1993).
Mean Productivity (MP) = (Yds+Yns)/2.
Percentage yield reduction due to drought = [(Yns – Yds)/Yns] *100
Yield stability index (YSI) =Yds/Yns (Bouslama and Schapaugh (1984) Genotypes with lower values of PYR and DSI, but with higher values of YSI, DRI and GM, are more drought tolerant.

RESULTS

Comparison of Error Mean Squares of the six environments revealed heterogeneity of variance. The Box and Cox (1959) algorithm suggested the following transformation of the original data:

$Y^{(\lambda)}$ =Geom*Log(Yield) (Log is the natural logarithm and $\lambda=0$ was used).

$Y^{(\lambda)}$ are the transformed variables; 'Geom' is the geometric mean ($\hat{Y}$), and $\hat{Y} = \ln^{-1}(\frac{1}{n}\sum \ln Y)$.

Results of ANOVA of the transformed data of individual environments revealed that the difference between the genotypes was significant at four of the six environments (Table 4). At E3 (Taba, 2012) and E6 (Huletegna Choroko, 2013) these differences were significant only at p=0.08. Large genotypic variance was observed within the tested genotypes of chickpea. The highest yielding genotypes at E1, E2, E3, E4, E5 and E6 were FLIP07-81C (m), Naatolii (g), Mastewal (f), Butajira local (b), Naatolii (g) and Naatolii (g), respectively.

Results of ANOVA

ANOVA of data combined over the six environments (Env) revealed very highly significant difference between the environments and very highly significant GxE effects (Table 3). Although the difference between genotypes (G) was significant at most of the environments, in the combined analysis these differences were significant only at p=0.08 (Table 3). This is due to the high GxE mean square against which the genotypic mean square was tested. The environments (Env) constituted 82.5% of the treatment sum of squares (Env + G + GxE) while genotypes and the GxE contributed 4.4 and 13.1%, respectively. Most of the variability in seed yield in this study was due to differences between the six environments. The highest yielding (68.7) environment (E2) gave yield which was more than double that of the lowest yielding (31.9) environment (E1) *(5.2 and 0.66 tons ha^{-1})*. The GxE interaction was about 3-fold that of the genotypic variations, indicating the importance of the GxE interaction in determining seed yield of chickpea and the need for further analysis to determine the stability and the adaptation pattern of each genotype

Table 3. Combined ANOVA of grain yield of 15 chickpea genotypes tested at six environments in southern Ethiopia in 2012/13

Source	DF	SS	MS	P-value	Percent SS Explained
Env	5	40004.2	8000.8***	<0.001	82.5
G	14	2130.7	152.2	0.08	4.4
GxE	70	6339.0	90.6***	<0.001	13.1
Rep(E)	12	297.4	24.8*	0.02	
Error	168	1943.5	11.6		
Total	269	50714.9			

R-Square = 0.96 C.V. = 6.8

Seed yield was low at E1, E3 and E5 (Jolle Andegna, Taba and Huletegna Choroko, during 2012, respectively) and high at E2, E4, and E6 (at each of the sites in 2013) (Table 4). This environmental variability was mainly due to the differences in the amount and distribution of rainfall during the growing period; rainfall was higher in 2013 at all three sites (Fig. 1). The correlation between the amount of seasonal rainfall and mean yield of the environments was 0.79 (p=0.06).

For instance, the total rainfall for the growing season at Taba was greater by about 270 mm in 2013 (E4) than in 2012 (E3) (638 vs 368 mm, an increase of 73%). As a result grain yield was increased by 116% (2644 vs 1217 Kg ha^{-1}). A similar trend was observed at Huletegna Choroko 2013 (E6) as compared to E5 (same location in 2012). Seasonal rainfall was higher by 56.2% (628 vs 402 mm and seed yield was higher by 111% (2799 vs 1322 Kg ha^{-1}). The largest difference in seed yield between the two years was observed at Jolle Andegna, where that at E2 (2013) was higher than that at E1 (2012) by 688% (5200 vs 658 Kg ha^{-1}); the seasonal rainfall was higher by 41.5% (737 vs 521 mm). The amount of rainfall in October and November of the year 2012 at Jolle Andegna (E1) was 15.8 mm and 0.0 mm, while the mean temperature was high during the grain filling stage. Besides, the amount of rainfall and its distribution was uneven, most of the days having no rain or rainfall of less than 5 mm. Therefore, the plants were stressed and exposed to forced maturity (50 vs 57 days to flowering and 102 vs 111 days to maturity, as compared to that in 2013).

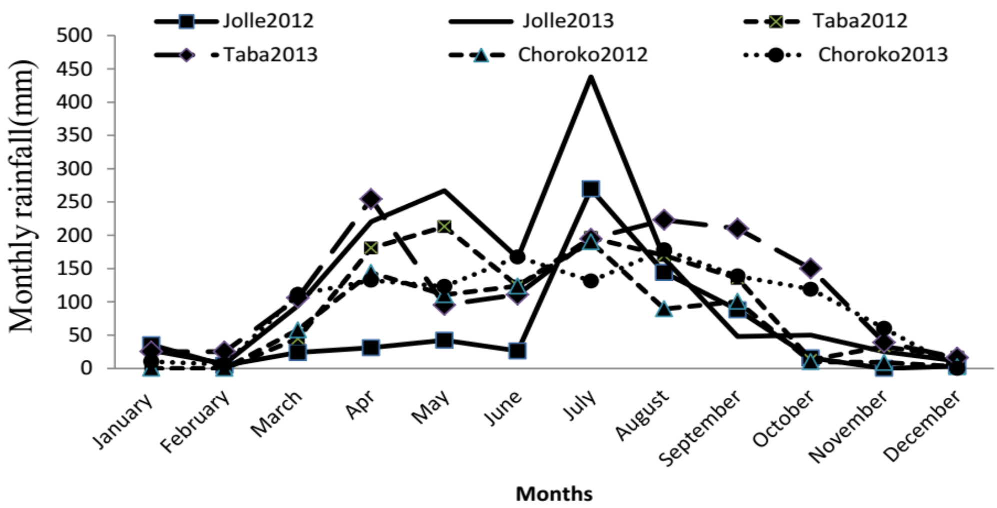


Figure 1. Rainfall at the three locations in southern Ethiopia during 2012 and 2013 (NMA, 2013)

The seven released varieties and the two landraces (genotypes 'a' to 'i') gave above average (50.1 units or 2450 Kg ha^{-1}) grain yield, while the elite lines (genotypes j to o) gave below-average seed yield except FLIP07-81C (m) which gave seed yield slightly above the grand mean (50.38 units) (Table 4). The elite lines were introduced from ICARDA as "Extra-early group", but previous results (Selamawit, 2012) showed that they belong to the medium (100-120 days to maturity) and late group (>120 days to maturity).This was also confirmed by the present work.

Although the two checks and the seven released varieties (a to i) had seed yield higher than the grand mean (except Cheffe (c)), and were superior to the elite lines (j to o), this performance lacks consistency over the six environments; ranks of genotypes were not constant over the six environments.

Table 4. Means of fifteen chickpea genotypes grown at six environments in southern Ethiopia in 2012/13

Genotypes	Code	E1	E2	E3	E4	E5	E6	Mean
Arerti	a	27.9^{f}	71.7^{ab}	43.9^{6*}	60.0^{abc}	49.4^{c}	60.1^{4*}	**52.2^{5*}**
Butajira local	b	34.0bcd^{e}	71.0^{abc}	41.1^{11}	62.7^{a}	53.4^{ab}	56.3^{12}	**53.1^{3}**
Cheffe	c	10.5^{g}	70.3^{abc}	46.8^{3}	58.1^{abc}	52.8^{b}	58.4^{6}	**49.5^{10}**
Ejeri	d	33.6^{bcde}	70.2^{abc}	46.3^{5}	61.6^{ab}	40.5^{e}	59.7^{5}	**52.0^{6}**
Habru	e	30.8^{ef}	68.7^{bcd}	42.9^{8}	55.4^{bcde}	47.9^{c}	60.3^{3}	**51.0^{8}**
Mastewal	f	34.2^{bcde}	70.9^{abc}	49.4^{1}	54.9^{bcde}	48.6^{c}	60.6^{2}	**53.1^{2}**
Naatolii	g	33.0^{de}	75.0^{a}	42.0^{9}	55.6^{bcde}	56.1^{a}	61.0^{1}	**53.8^{1}**
Shasho	h	37.8^{ab}	66.2^{bcde}	43.3^{7}	57.7^{abcd}	53.0^{b}	58.4^{8}	**52.7^{4}**
Wolayita local	i	35.9^{abcd}	70.4^{abc}	41.2^{10}	61.6^{ab}	40.5^{e}	57.4^{11}	**51.2^{7}**
FLIP03-53C	j	30.6^{ef}	61.6^{e}	41.0^{12}	50.5^{e}	44.8^{d}	57.5^{10}	**47.7^{12}**
FLIP03-102C	k	26.8^{f}	68.0^{bcd}	46.7^{1}	50.9d^{e}	30.5^{g}	54.9^{13}	**46.3^{14}**
FLIP03-128C	l	37.6^{abc}	67.2^{bcd}	37.0^{15}	54.6bcde	36.0^{f}	53.6^{15}	**47.7^{11}**
FLIP07-81C	m	38.6^{a}	69.0^{bcd}	47.4^{2}	56.6^{abcde}	32.8^{g}	57.9^{9}	**50.4^{9}**
FLIP08-60C	n	33.2^{cde}	66.1^{cde}	37.7^{14}	53.7cde	33.1^{g}	58.4^{7}	**47.0^{13}**
FLIP07-27C	o	33.8^{bcde}	64.4^{de}	38.1^{13}	55.7^{abcde}	19.2^{h}	54.3^{14}	**44.3^{15}**
Mean		**31.9**	**68.7**	**43.0**	**56.6**	**42.6**	**57.9**	**50.1**
LSD		**4.14**	**5.57**	**NS**	**7.00**	**2.79**	**NS**	**NS**

NS = not significant; * = Ranks of genotypes; E1 = Jolle Andegna 2012, E2= Jolle Andegna 2013, E3 =Taba 2012, E4 = Taba 2013, E5 = Huletegna Choroko 2012, and E6 = Huletegna Choroko 2013.

Genotype FLIP03-128C (l) for example ranked 3rd at E1, but its ranks were greater than 10 in the remaining environments. Entry Naatolii (g) was the highest yielding genotypes at E2, E5 and E6, respectively, but ranked 10th, 9th and 9th at E1, E3, and E4, respectively.

Although ANOVA is important in detecting the presence of GxE interaction, it is not capable to explain the type of the GxE interaction, the contribution of each genotype or each environment to the total GxE interaction and the relationship between the genotypes and the environments (which genotype is better adapted to which environment, whether there are genotypes adapted to all environments or to specific environments). Stability analysis sheds light to many of these questions.

Stability Analysis

The GxE (Linear) interactions in Eberhart and Russell's (1966) regression model were not significant (results not presented); the slopes (b_i), which are used as a measure of the responsiveness of the genotypes to change in environments, did not vary for the different genotypes included in the study; neither did the slope (b_i) of each genotype deviate from unity (Table 5), which indicates that all the tested genotypes had average responsiveness.

There was no correlation between yield and the bi values (r = -0.18; the rank correlation was -0.22 and were non-significant). The range of the slopes was narrow (0.75 to 1.35) and this may be the reason for the non-significant correlation between the slopes and grain yield.

On the other hand, the pooled deviation was highly significant (results not shown). It was also significant for 13 of the 15 genotypes (Table 5), which entails that the pattern of the highly significant GxE interaction could not be explained by regressing varietal means on environmental indices. Indeed, this model explained only 12.2% of the GxE interaction. This can also be observed from the very low R^2 values for each genotype (Table 5).

Wricke's ecovalence (Wi), Deviation from regression (S^2d_i) and AMMI Stability Value (ASV) assigned similar stability ranks to the 15 genotypes; the correlations between these ranks being 0.97^{***}, 0.87^{***} and 0.93^{***}, all very highly significant. If the whole range of stability by Wi, S^2d_i or ASV is divided into three categories, the lowest one-third, the middle one-third and the highest one-third, then genotypes can be classified into three corresponding stability groups; high, intermediate and low stability, respectively. All three assigned Ejeri (d), Habru (e), Wolayita local (i), Mastewal (f) and FLIP03-53C (j) into the high stability group. The genotypes assigned to medium and low stability groups were the same for W_i and S^2d_i; the two differing from ASV by assigning FLIP03-128C (m) in the Medium Stability and FLIP03-102C (k) in the low stability groups; these two genotypes were assigned into the opposite groups by ASV. We can, therefore, conclude that Cheffe (c), Naatolii (g), FLIP03-102C (k), FLIP07-81C (m), and FLIP07-27C (o), were the most unstable genotypes.

Table 5. Mean grain yield, Wricke's ecovalence (Wi), slope (bi), deviation from regression (S^2d_i) and AMMI Stability Values (ASV) of the 15 chickpea genotypes tested in 2012-2013 in southern Ethiopia

Genotypes	Mean	Wi	bi	S^2d_i	R^2	ASV	RY	RW	RD	RASV
Arerti	52.15	63^{***}	1.12	4.16^{***}	0.21	3.6869	5	6	6	8
Butajira local	53.06	117^{***}	0.96	9.91^{***}	0.01	3.7163	3	10	10	9
Cheffe	49.48	579^{***}	1.37	38.45^{***}	0.21	10.667	10	15	15	15
Ejeri	52.00	27	1.04	1.81	0.05	1.8277	6	1	1	2
Habru	51.01	32	0.99	2.78^{*}	0.00	2.4989	8	2	3	5
Mastewal	53.08	45^{*}	0.91	2.55	0.18	1.6122	2	4	2	1
Naatolii	53.78	156^{***}	1.02	11.55^{***}	0.00	5.1878	1	12	12	12
Shasho	52.71	110^{***}	0.75	4.58^{***}	0.51	3.0294	4	9	7	6
Wolayta local	51.16	44^{*}	1.02	3.69^{***}	0.01	2.2411	7	3	5	4
FLI P03-53C	47.65	62^{***}	0.83	2.93^{*}	0.43	1.8954	12	5	4	3
FLI P03-102C	46.27	139^{***}	1.09	10.83^{***}	0.06	3.606	14	11	11	7
FLI P03-128C	47.66	100^{***}	0.90	7.51^{***}	0.08	4.1896	11	8	9	11
FLI P07-81C	50.38	160^{***}	0.91	13.08^{***}	0.04	6.058	9	13	13	13
FLI P08-60C	47.02	78^{***}	1.02	6.59^{***}	0.01	3.9529	13	7	8	10
FLIP07-27C	44.26	401^{***}	1.07	33.61^{***}	0.01	9.7807	15	14	14	14

*significant at P<0.05; *** is significant at P<0.001; W_i=Wricke's Ecovalence; b_i=Slopes from regression; S^2d_i=Deviations from regression; R^2=Coefficient of Determination; ASV=AMMI Stability Value; RY=Ranks by Yield; RW=Ranks by Wricke's Ecovalence; RD=Ranks by Deviations from regression; RASV=Ranks by AMMI Stability Values.

There was no correlation between ranks by yield on one side and ranks by W_i, S^2d_i; and ASV on other side (r=0.25, 0.33, and 0.31, respectively; all statistically non-significant). Simultaneous selection for high yield and high stability is possible. The 15 genotypes are almost evenly distributed into all possible combinations of levels of yield and levels of stability (low, medium and high). For example, Mastewal (f) is a high yielding variety with high stability, while Natolii (g) which is also a high yielding variety has low stability. FLIP03-53C (j) is a low yielding genotype but with high stability while FLIP03-102C (k) and FLIP07-27C (o) were also low yielding but at the same time they had low stability.

Additive Main Effects and Multiplicative Interaction (AMMI)

The first two interaction principal component axes (IPCA 1 and IPCA 2) explained 65.8 and 21.3%, respectively, and together 87.1% of the interaction Sum of Squares (Table 6).

Table 6. Analysis of variance for AMMI model for grain yield of chickpea genotypes evaluated across six Environments

Source	D.f.	SS	MS	p-value	Percent of Gx E explained
Total	269	50714.8			
Treatments	89	48473.9	544.7	<0.001	
Genotypes	14	2130.7	152.2	0.08	
Environments	5	40004.2	8000.8	<0.001	
Block	12	297.4	24.8	0.02	
Interactions	70	6339.0	90.6	<0.001	
IPCA 1	18	4172.7	231.8	<0.001	65.8
IPCA 2	16	1351.8	84.5	<0.001	21.3
IPCA 3	14	498.9	35.6	<0.001	7.9
IPCA 4	12	182.1	15.2	0.218	2.9
IPCA 5	10	133.8	13.4	0.328	2.1
Error	168	1943.5	11.6		

Df=degree of freedom; SS =sum of squares; MS= mean squares

IPCA 3 accounted for only 7.9% of the interaction sum of squares. AMMI-II was, therefore, the most appropriate model. The first two IPCA divided the environments into four separate polygons. E1 and E5, each in separate polygon, were two environments with the highest contribution to the GxE interaction (32.6 and 45.9%, respectively and a total of 78.5%) (Fig. 2).Genotypes on or near the vertex of polygons, far from the center of the plot also contributed the most to the total GxE interaction and were therefore unstable. They had positive interaction (GE) with the environment nearest to their vertex and had the potential to give high yield (G+GE) at this environment, this being decided by their overall genotypic effect (G).

FlIP03-128C (l) had high positive interaction with E1. Butajira local (b), Cheffe (c) and Naatolii (g) had high positive interaction with Huletegna Cheroko-2012 (E5). Genotype Shasho (h) had large positive interaction with both E1 and E5. Cheffe (c) and FLIP03-102C (k) had positive interaction with E3 (Fig. 2).

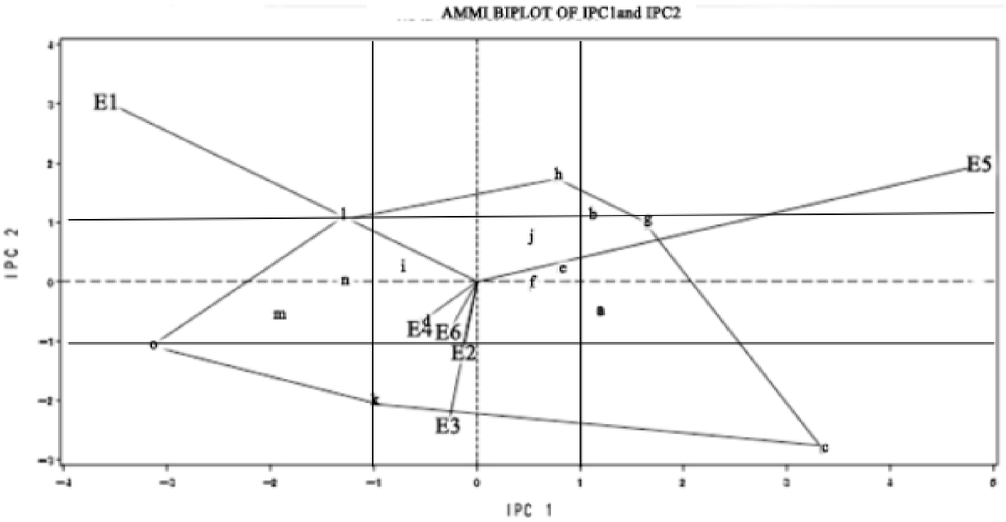
The genotypes at or near the vertex of polygons on Fig. 2, such as FlIP03-128C (l), Butajira local (b), Cheffe (c), Naatolii (g), Shasho (h), FLIP03-102C (k), FLIP08-60C (n), FLIP07-27C (o), FLIP07-81C (m), Arerti (a), manifested large interaction and were, therefore, unstable; they constituted 90% of the GxE Sum of Square.

Genotypes placed near the origin, such as Ejere (d), Habru (e), Mastewal (f), Wolayita local (i), and FLIP03-53C (j) contributed very little (10%) to the total GxE interaction and were therefore stable. Among these genotypes, Ejere (d), Habru (e), Mastewal (f), and Wolayita local (i) gave above average mean yield and can be recommended for wide adaptation. These were also identified by the univariate stability parameters, W_i, S^2d^i and ASV_i.

Genotype plus Genotype by Environment interaction (GGE) biplots

The first two components explained 83.3% of the total GGE variation with component 1 and 2 explaining 61.8

and 21.5%, respectively (Fig.3). E1 (Jolle 2012) and E5 (Huletegna Choroko-2012), two environments with the lowest mean yields, had the longest vectors, indicating that these are environments with high discriminating power (Fig.3). The yield range was very big at these two environments. Indeed the difference between the 15 genotypes was statistically non-significant at E3 (Taba, 2012) (p=0.08) and E6 (Huletegna Choroko, 2013 (p=0.06)), while at E1 and E5 the differences were very highly significant (p<0.0001); at E4 the difference was significant at p=0.03. E2, E3, E4 and E6 had short vectors and were badly modeled by the two components Genotype FLIP07-27C (o) had very large negative interaction with E5, small negative interaction with the remaining environments except E1 where it had a small positive interaction (Fig. 2).



E1=Jolle Andegna 2012, E2=Jolle Andegna, 2013; E3=Taba, 2012, E4=Taba, 2013, E5= Huletegna Choroko, 2012, E6=Huletegna Choroko, 2013

Figure 2. AMMI biplot for 15 chickpea genotypes tested at three locations in southern Ethiopia in 2012/13

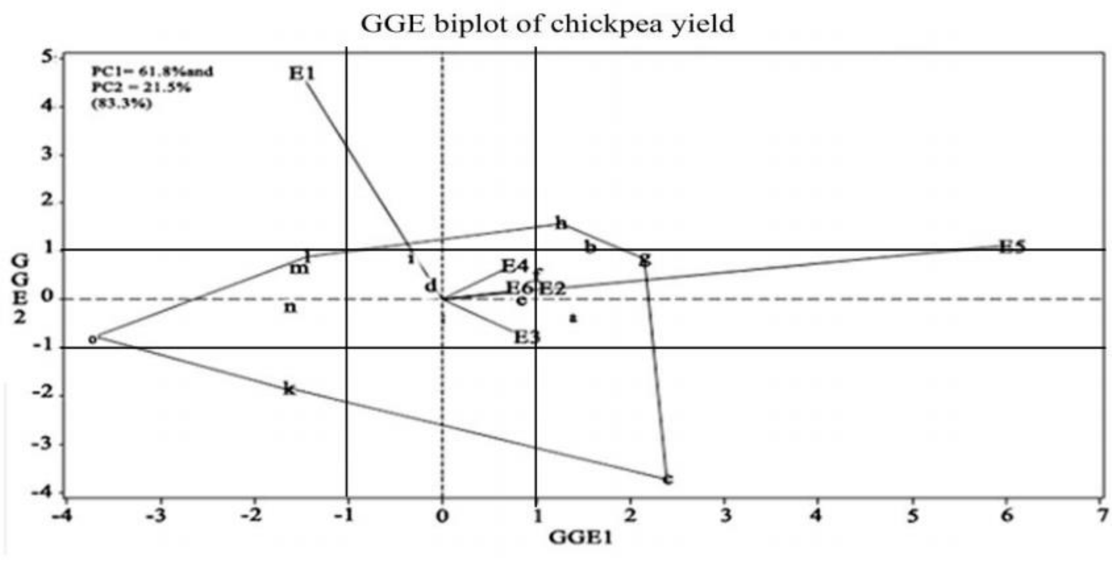


Figure 3. GGE bi-plot showing which cultivar yielded best in which environment

GGE biplot which used the first two components divided the six environments into three sectors; E1 (Jolle-2012) was separated from all other environments. Indeed the correlations between yields at this environment and yields at all other environments was negative; the largest negative correlation being that with E3 (-0.31) and with

E5 (-0.25). The remaining five environments were in the same cluster; the correlation between yields at these environments being positive. For example the rank correlations between yields at the highest yielding environment E2 and the remaining four environments E3, E4, E5 and E6 were 0.44, 0.57*, 0.61** and 0.52*, respectively. E3 had the weakest positive correlation with the remaining four environments and was in a separate polygon near the cluster of the four environments.

FLIP03-128C (l), and FLIP07-81C (m) are near the polygon of E1 and ranked 3rd, and 1st at this environment. Shasho (h) was also at the boundary between E1 and E5 where it ranked 2nd, and 3rd, respectively. E1 was the lowest yielding environments and the three genotypes can be classified as specifically adapted to low yielding environments.

E2 (Jolle-2013), E4 (Taba-2013), E5 (Choroko-2012) and E6 (Choroko-2013) were in the same sector very close to each other (Fig.3). They ranked the genotypes in a very similar manner. Although the mean yield at E5 was very similar to that at E3 (42.6 vs 43.0), it was closer to E2, E4 and E6 than to E3.

The winning genotypes in the sector of E2, E4, E5 and E6 were Butajira local (b) and Naatolii (g). Butajira local (b) ranked 3rd 1st 2nd and 12th at E2, E4, E5 and E6 while Naatolii (g) ranked 1st, 9th, 1st, and 1st, respectively at the four environments. The mean of these four environments, except E5, (Huletegna Cheroko 2012) (42.6) was much higher than the grand mean (50.1) and ranged from 56.7 to 68.7; the genotypes associated with them can, therefore, be considered as specifically adapted to high yielding environments. Cheffe (c) is specifically adapted to E3 where it ranked 3rd. Its rank in E2, E4, E5 and E6 was also less than 6, but it was ranked 15th in E1, giving the lowest yield. This genotype can also be considered as specifically adapted to high yielding environments. Genotype Arerti (a) was in the sector of E3. Although it was much nearer to the center of the plot than Cheffe (c), it can be considered as specifically adapted to high yielding environments and ranked 6th, 3rd, 5th, 4th and 6th at E2, E3, E4, E5, and E6, respectively, but 13th at E1.

Genotypes near the center of the plot, Ejeri (d), Habru (e), Mastewal (f), Wolayita local (i), and FLIP03-53C (j) were stable. All except FLIP03-53C (j), gave yields higher than the grand mean and can be considered as widely adapted genotypes. FLIP03-102C (k), FLIP08-60C (n) and FLIP07-27C (o), were not adapted to any of the environments, their mean yields were below the grand mean.
Based on stability analyses using three univariate and two multivariate (AMMI and GGE) stability parameters, the 15 chickpea genotypes can be categorized into the following four groups:

Group I: - Those specifically adapted to high yielding environments (E2, E4, E5 and E6); E3 was adjacent to this group and shared similar genotypes with the four environments. These were Arerti (a), Butajira local (b), Cheffe (c) and Naatolii (g).

Group II: -Those specifically adapted to low yielding environments (E1)-Shasho (h), FLIP03-128C(l) and FLIP07-81C (m).

Group III: - Genotypes adapted to all environments (wide adaptation) – Ejeri (d), Habru (e), Mastewal (f), Wolayita local (i), FLIP03-53C (j).

Group IV: - Those not adapted to any environment - FLIP03-102C (k), FLIP08-60C (n) and FLIP07-27C (o).

Various measures of drought tolerance have been calculated for the four groups and these are given in Table 7. For this analysis E1 (Jolle Andegna in 2012) was used as stress environment while E2 (Jolle Andegna in 2013) was used as non-stress environment.

Table 7. Drought Tolerance measures of three groups of chickpea genotypes grown in 2012/13 at three locations in southern Ethiopia

Type	YLDA	YLDB	MEAN	PYR	YSI	DSI	DRI	GM	MP
High yielding	5.08	62.00	26.63	91.88	0.08	0.91	0.07	17.37	33.54
Low yielding	8.81	48.33	22.17	81.73	0.18	0.79	0.24	20.63	28.57
Non adapted	6.16	44.22	18.79	85.83	0.14	0.84	0.14	16.37	25.19
Widely adapted	6.71	50.87	23.29	86.57	0.13	0.85	0.14	18.44	28.79

YLDA=Yield under moisture stress (at E1, Jolle Andegna, 2012); YLDB=Yield under no moisture stress (E2, Jolle Andegna, 2013); MEAN=Mean of the six environments; PYR=Percent Yield Reduction; YSI=Yield Stability Index; DSI=Drought Susceptibility Index; DRI=Drought Resistance Index; GM=Geometric Mean; MP=Mean Productivity.

Comparison of group I and II genotypes revealed that genotypes adapted to high yielding environments had the highest seed yield under no stress (YLDB) (62.0 vs 48.3; 28.4% yield advantage), the highest mean yield (MEAN) (26.6 vs 22.2) and mean productivity (MP) (33.5 vs 28.6), while genotypes adapted to low yielding environments had the highest mean yield under moisture stress (YLDA) (E1) (8.8 vs 5.1; 72.5% yield advantage), the highest geometric mean yield (GM) (20.6 vs 17.4), the highest Yield Stability Index (YSI) (0.18 vs 0.08), the highest Drought Resistance Index (DRI) (0.24 vs 0.07), the lowest Percent Yield Reduction (PYR) (81.7 vs 91.9), and the lowest Drought Susceptibility Index (DSI) (0.79vs 0.91). The other two groups had intermediate values for these parameters.

The genotypes specifically adapted to the most drought stressed environment might have been specifically bred for drought tolerance, and selection methods using some of the drought indices may have been used during evaluation. Two of these, FLIP03-128C (l) and FLIP07-81C (m), were indeed extra-early chickpea genotypes received in 2011 from ICARDA. They can be recommended for areas where the rainfall is low most of the years and the probability of high rains is very low. Most growing areas in the rift valley are of this type. Arerti (a), Butajira local (b), Cheffe (c) and Naatolii (g) are adapted to high yielding environments and should be grown in mid-altitude areas adjacent to the rift valley where rainfall is relatively high most of the years. Ejeri (d), Habru (e), Mastewal (f), and Wolayita local (i), are widely adapted genotypes and can be grown in most of the areas suitable for chickpea growing.

Modern methods of weather forecast can be used to predict the suitability of the coming season for chickpea production. If high rainfall is expected for the growing season even in areas with severe moisture stress, varieties with high potential yield can be distributed to farmers; at least the stable varieties can be substituted for those adapted to low yielding environments. Farmers can get some bonus from these relatively high yielding varieties.

DISCUSSION

Many authors have studied the performance of chickpea genotypes over many environments varying in degree of moisture stress (Getachew Tilahun *et al*., 2015; Farshadfar *et al*., 2011; Geletu Bejiga and Ketema Daba, 2003; Upadhyava *et al*., 2013; Yucel and Mart, 2014). In agreement with our results all these authors reported significant E, G and GxE effects. In these studies the environment constituted more than 80% of the treatment sum of squares, which is in agreement with our results (82.5%) and is the major determinant of the observed variability in grain yield of chickpea while the share of the GxE effects was higher than that of G. The contribution of E was smaller in the studies by Getachew Tilahun *et al*. (2015) (53%), Fekadu Gurmu *et al.* (2011) (69.7%) and Mulugeta Atnaf *et al.* (2013) (25.6%); GxE constituted 59.6% in this study). In most of these studies the most discriminating environments were the highest yielding environments, while in our study the two low yielding environments, E5 and E1, were the most discriminating environments.

Many studies on chickpeas showed that linear regression could not explain much of the significant GxE interaction; the GxE linear component was non-significant while the pooled deviation was significant (Fekadu Gurmu *et al*., 2011; Getachew Tilahun *et al.*, 2015; Kenga *et al.*, 2003) implying that there is either no relationship, or no simple relationship (the relation may be explained by fitting quadratic component or even log-linear regression may be appropriate) between the GxE interaction and the environmental values and hence no prediction can be made from linear regression (Perkins and Jinks, 1971). Linear regression explained only 15.4% of the GxE interaction of soybean yield in the investigation by Fekadu Gurmu *et al*. (2011), a little higher than the one in our study (13%).We found no relationship between yield and the stability parameters; the rank correlation between W_i, S^2d_i and bi on one side and grain yield on the other side was 0.25, 0.33 and -0.22, all statistically non-significant, contradicting the notion that varieties with $b_i < 1$ are adapted to low-yielding environments while those with b_i-values > 1 are adapted to high-yielding environments (Eberhart and Russel, 1966; Finlay and Wilkinson, 1971). In agreement with our results Astveit and Astveit, (1984) and Nurminiemi (1995), however found no correlation between yield and b_i-values. Getachew Tilahun *et al.* (2015) found positive correlation between Wricke's ecovalence (W_i) and seed yield; high yielding genotypes had higher ecovalence and were adapted to high yielding environments, which contradict our results.

The first two components of AMMI (IPC1 and IPC2) were used by Fekadu Gurmu *et al.* (2011), while the first two components of G+GE (GGE1 and GGE2) were used by Mulugeta Atnaf *et al.* (2013) to shed light on the significant GxE interaction of grain yield in soybean. Muhammad Amir *et al.*, (2015), Upadhyava *et al.*, (2013) and Farshadfar *et al.*, (2011) also used the first two components of GGE to study GxE interaction in grain yield of chickpea. These two components explained more than 75% of the GxE interaction or of the GGE sum of square in these studies and the researchers were able to classify the environments into different groups depending on their potential yield and the pattern of their interaction with the genotypes included in the study. There was positive correlation between relatively high yielding environments, for example irrigated and rain fed environments, while the correlation between environments with severe stress and other environments (non-irrigated and irrigated) was not significant (Upadhyava *et al.*, 2013). In our study yields under the most severe drought stress environment (Jolle Andegna in 2012 (E1)) and yields at the highest yielding environment (the same site in 2013 (E2)), were negatively correlated.

Sometimes a large heterogeneous production area is classified into more homogenous mega-environments by AMMI or GGE analysis. Appropriate varieties could then be developed for each mega-environment (Farshadfar *et al.*, 2011) which enabled the exploitation of repeatable GxE interactions such as differences in soil types, altitude zones and the amount of annual rainfall. Genotypes could also be classified into various categories depending on their potential yield and the pattern of their interaction with the environments. High yielding and stable genotypes with wide adaptation, unstable genotypes that are specifically adapted to either high yielding or low yielding environments and those adapted to no environment and should be discarded from further investigation, could be identified. Mulugeta Atnaf *et al.* (2013) identified the most discriminating and most representative environments for soybean production in western Ethiopia.

Some physiological and drought tolerance characteristics such as Percent Yield Reduction (PYR), Drought Tolerance Index (DTI), Root Length Density (RLD) and the Maximum Root Depth (RDp) were also used to evaluate chickpea genotypes for drought tolerance (Geletu Bejiga and Ketema Daba, 2003; Gaur *et al.*, 2008;Ulemale *et al.*, 2013; Getachew Tilahun *et al.*, 2015;). Drought tolerant genotypes have minimum Percent Yield Reduction (PYR) and the highest Drought Tolerance Index (DTI). They also have the highest RLD and RDp. Gaur *et al.* (2008) have found high variability for such traits in collections of chickpea at ICRISAT. They suggested that selection of early flowering, early podding and early maturing (85-100 days) lines with vigorous early growth improves tolerance to terminal drought. Although we did not take data on RLD and RDp, the genotypes adapted to the low yielding environment (Jolle, 2012, E1) such as FLIP03-128C(l) and FLIP07-81C (m) had the tallest plants. Root length is believed to be proportional to plant height and these genotypes are believed to possess higher RLD and RDp values than genotypes adapted to non-stress environments such as Arerti (a), Butajira local (b), Cheffe (c) and Naatolii (g).

Ulemale *et al*. (2013) reported the lowest and highest PYR of 11.67 and 60.95% and the maximum and minimum DRI of 1.52 and 0.29. In our experiment these values were 80.7 and 96.8% and0.255 and 0.009 for Shasho (h) and Cheffe (c), respectively. Shasho (h) was adapted to low yielding environments while Cheffe (c) was adapted to high yielding environments. The mean PYR and DRI for the genotypes adapted to high yielding and low yielding environments were 91.9 vs 81.7 and 0.07 vs 0.24, respectively. Widely adapted genotypes had intermediate values (86.6 and 0.14, respectively). The very high values for PYR and very low values for DRI in our experiment might be due the high Drought Intensity Index (DII) of 0.873, which indicates severe drought stress. Yield under the most severe drought stress (E1) (31.89) was only 46.4% of that under the most favorable conditions (E2) (68.71) (12.7% in the original scale; 0.6584 vs 5.2 t ha^{-1}). In the study of Yucel and Mart (2014) grain yield was reduced by 43% due to drought stress. In our experiment seed yield was reduced due to moisture stress by 53.4% in the transformed scale and by 87.3% in the original scale (ton ha^{-1}).

CONCLUSIONS AND RECOMMENDATIONS

Long term climatic data reveals that the southern rift valley can be classified into mid-altitude chickpea growing areas with relatively higher annual rainfall and its better distribution and areas with lower altitude and lower amount of rainfall accompanied with uneven distribution in most of the years. Butajira (Jolle Andegna) and Taba belong to the first group while Halaba (Huletegna Choroko) belongs to the second group. This is repeatable GxE interaction which can be exploited by recommending genotypes adapted to high yielding environments such as Butajira local, Naatolii, Cheffe and Arerti for mid-altitude chickpea growing areas similar to Butajira and Taba and distributing genotypes adapted to low yielding environments such as FLIP03-1280, FLIP07-81C and Shasho in more moisture-stressed areas similar to Halaba (Huletegna Choroko). However the unrepeatable GxE patterns such as manifested through the big difference in the amount of rainfall between the 2012 and 2013 growing seasons at the same location, should also be taken into consideration. If the weather forecast indicates that severe moisture stress is anticipated for the coming growing season, then genotypes initially recommended for low-yielding areas such as FLIP03-1280, FLIP07-81C and Shasho may be recommended for the more favorable regions such as Butajira and Taba and the vice versa, if the anticipated growing season is a favorable one, genotypes initially recommended for more favorable zones such as Butajira local, Naatolii, Cheffe and Arerti can be distributed in areas like Halaba. The widely adapted genotypes such as Ejeri, Habru, Mastewal and Wolayita local can be made available to users as alternatives in both favorable and unfavorable moisture stress areas. The high yields during these rarely occurring favorable growing seasons are crucial for the food security of such areas; the surplus grain can be stored and used over a longer period.

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REFERENCES

Aastveit A.H. and Aestveit K. 1984. Genetic variation of developmental stability in barley. *Hereditas* 101:155-170.

Becker H.C. and Léon J. 1988. Stability analysis in plant breeding. Plant Breeding 101:1-23.

Bouslama M. and Schapaugh W.T. 1984. Stress tolerance in soybean: evaluation of three screening techniques for heat and drought tolerance. *Crop Sci*. 24: 933-937.

Box, G.E.P. and Cox, D.R. 1964. An analysis of transformation. *J. R. Stat. Soc. Series B. Stat. Methodol.* 26:211-243.

CSA (Central Statistical Agency of the FDR of Ethiopia). 2014/2015. Report on area and production of major crops. Private peasant holdings, Meher season. Volume I. Statistical Bulletin 578. Addis Ababa.

Eberhart S.A. and Russell W.A. 1966.Stability parameters for comparing varieties. *Crop Sci*. 6: 36-40.

FAOSTAT. 2013. Production: crops. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor. Accessed on 16/03/2016.

Farshadfar E., Hassen Z. and Reza M. 2011. Evaluation of Phenotypic Stability in Chickpea Genotypes using GGE bi-plot Analysis. *Annals Biol. Sci*. 2(6): 282-292.

Fekadu Gurmu, Hussein Mohammed, Asrat Asfaw, Getinet Alemaw and Fitsum Alemayehu. 2011. Additive Main Effect and Multiplicative Interaction Analysis of grain yield of soybean genotypes in Ethiopia. *Trop. Agric*. (Trinidad). 88 (2): 69-78.

Fernandez C.G.J. 1993. Effective selection criteria for assessing plant stress tolerance. In: C. G. Kuo, (ed). Adaptation of Food Crops to Temperature and Water Stress, AVRDC, Shanhua, Taiwan.pp. 257-270.

Fisher R.A. and Maurer R. 1978. Drought resistance in spring wheat cultivars; Grain yield responses. *Aust. J. Agric. Res*. 29: 897-912.

Gauch H.G. 1988. Model selection and validation for yield trials with Interaction. *Biometrics* 44: 705–715.

Getachew Tilahun, Firew Mekbib, Asnake Fikre, and Million Eshete. 2015. Genotype x environment interaction and stability analysis for yield and yield related traits of kabuli-type chickpea (*Cicer arietinum* L.) in Ethiopia. *Afr. J. Biotechnol*. 14(18): 1564-1575.

Gaur P.M., Lakshmanan K. and Junichi K. 2008. Improving Drought-avoidance root traits in chickpea (*C. arietinum* L.) – Current status of research at ICRISAT. *Plant Prod. Sci*. 11(1):3-11.

Geletu Bejiga and Ketema Daba. 2003. Breeding Chickpea for wide adaptation. In: Ali K., Keneni Gemechu, Ahmed Seid, Molhatra R., Beniwal S., Makkouh K., and Halila M.H. (Eds.). Food and forage legumes, Proceedings of the workshop on Food and Forage legumes, 22-26 September, 2003. Addis Ababa, Ethiopia, EIAR and ICARDA. pp. 59-66.

Hussein M.A., Bjornstad A. and Aastveit A.H. 2000.Sas G x Estab, A SAS program for computing genotype x environment stability statistics. *Agron. J*. 92: 454–459.

Kenga R., Alabi S.O. and Gupta. 2003. Yield stability of sorghum hybrids and parental lines. *Afr. Crop Sci. J.* 11: 65-73.

MoARD (Ministry of Agriculture and Rural Development). 2015. Crop variety Register. ISSUE Numbers 10. Addis Ababa.

Muhammed A. M., Muhammed I., Hina A., Tariq M. S., and Babar N. A. 2015. GGE Biplot Analysis based selection of superior chickpea (*Cicer arietinum* L.) inbred lines under variable water environment. *Pak. J. Bot.* 47(5): 1901-1908.

Mulugeta Atnaf, Sisay Kidane, Seltene Abadi and Zelalem Fisha. 2013. GGE biplots to analyze soybean multi-environment yield trial data in north western Ethiopia. *J. Plant Breed. Crop Sci*. 5 (12): 245-254.

NMA (National Meteorology Agency) 2013. http://www.ethiomet.gov.et/ accessed on December 2014.

Nurminiemi M. 1995. *Environmental stability of Nordic barley materials*. PhD Thesis. Agricultural University of Norway. 230pp.

Onwueme I.C. and Sinha, T.D. 1991. Field crops production in tropical Africa. Technical Center of Agricultural and Rural Cooperation (TCA), The Netherlands. 552pp.

Perkins J.M. and Jinks J.L. 1971. Specificity of the interaction of genotypes with contrasting environments. *Heredity* 26: 463-474.

Rosielle A.A. and Hamblin J. 1981. Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Sci*. 21:943-946.

Selamawit, K. 2012. *Evaluation of phenotypic and genotypic variability for growth, yield and yield components of extra early chickpea (Cicer arietinum L.) genotypes in Meskan Woreda*, *Gurage Zone*, *SNNPR*. MSc Thesis. Hawassa University, College of Agriculture.

SAS Institute Inc. 2008. SAS/STAT® 9.2. Cary, NC, USA.

Ulemale C.S., Mate S.N. and Deshmukh D.U. 2013. Physiological Indices for Drought Tolerance in Chickpea (*Cicer arietinum* L.). *World J. Agric. Sci*. 9(2): 123-131.

Upadhyaya H.D. Dronavalli N., Dwivedi S.L., KashiwagiJ., Krishnamurthy L., Pande S., Sharma H.C., Vadez V., Singh S., Varshney R.K., and Gowda C.L.L. 2013. Mini Core Collection as a Resource to Identify New Sources of Variation. *Crop Sci*. 53: 2506–2517.

Wricke G.1962. Bereine method zurerfassung der ökologischen Streubreite in feldversuchen. *Z. Pflanzenzüchtg* 47: 92-96.

Yucel D. and Mart D. 2014. Drought Tolerance in Chickpea (*Cicer arietinum* L.) Genotypes. Turkish J. Agric. Nat. Sci. Special issue 1: 1299-1303.

Zobel R. Wright, J., and Gauch, G.1988. Statistical analysis of a yield trial. *Agron. J*. 80: 388–393.