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Genotype x environment interaction and stability analysis for yield and yield related traits of Kabuli-type Chickpea (*Cicer arietinum* L.) in Ethiopia

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Chickpea is the major pulse crop cultivated in Ethiopia. However, its production is constrained due to genotype instability and environmental variability. This research was carried out to examine the magnitude of environmental effect on yield of chickpea genotypes and to investigate the stability and adaptability of genotypes under different agro-ecologies. Seventeen (17) genotypes were evaluated in randomized complete block design (RCBD) with four replications in five locations. Various stability indices were used to assess stability and genotype by environment performances. Combined analysis of variance (ANOVA) for yield and yield components revealed highly significant (P≤0.01) differences for genotypes, environments and their interaction. The significant interaction showed genotypes respond differently across environments. At Akaki, Chefe Donsa, Debre Zeit, Dembia and Haramaya, top performing genotype were DZ-2012-CK-0001 (2933 kg/ha), Arerti (3219 kg/ha), Arerti (3560 kg/ha) DZ-2012-CK-0013 (2675 kg/ha) and Arerti (2019 kg/ha), respectively. The first two PCs explained 74.45% of the variance. Based on ASV value, DZ-2012-CK-0002 were most stable genotypes. As per AMMI biplot, Arerti and DZ-10-4 were most widely adapted genotypes. Dembia and Haramaya were most discriminative environments for genotypes. Debre Zeit and Chefe Donsa were favorable environment for genotype. Genotypes DZ-2012-CK-0004, DZ-2012-CK-0010, DZ-2012-CK-0013, DZ-2012-CK-0007 and DZ-10-4 are recommendable to Akaki, Chefe Donsa, Debre Zeit, Dembia and Haramya, respectively.

Key words: AMMI, ASV, clustering, phenologic traits, Kabuli, univariate statistics.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a cool season legume that ranks third among the pulses in area and production worldwide. It is grown on around 1.1 million hectare with 9 metric tons global production (Babar et al., 2009). The

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Abbreviations: E, Environments; **G,** genotypes; **RCBD,** randomized complete block design.

Table 1. Geographic and environmental conditions of experimental area.

Trial site	Soil type	Altitude (masl)	Rainfall average (mm)	Temperature (°C)		Geographical position	
				Min	Max	Latitude (N)	Longitude (E)
Akaki	Vertisol	2120	1055	10.36	22.3	08°52’	38°48’
Chefe Donsa	Vertisol	2450	950	10.5	23.2	08°52’	39°08’
Dembia	Vertisol	1885	1000	14.0	29.2	12°32830’	37°22065’
Debre zeit	Vertisol	1950	851	10.8	26.9	08°44’	38°58’
Haramaya	Vertisol	1980	780	15.8	24.3	9°26’	42°30’

Source: Debre Zeit Agricultural Research Center (2012).

Table 2. List of Kabuli-type chickpea genotypes included in the experiment

Entry no.	Entry name	Entry no.	Entry name	Entry no.	Entry name
1	DZ-2012-CK-0001	8	DZ-2012-CK-0008	15	EJERE (SC)
2	DZ-2012-CK-0002	9	DZ-2012-CK-0009	16	HABRU (SC)
3	DZ-2012-CK-0003	10	DZ-2012-CK-0010	17	DZ-10-4
4	DZ-2012-CK-0004	11	DZ-2012-CK-0011		
5	DZ-2012-CK-0005	12	DZ-2012-CK-0012		
6	DZ-2012-CK-0006	13	DZ-2012-CK-0013		
7	DZ-2012-CK-0007	14	ARERTI (SC)		

Kabuli type chickpeas are characterized by white-colored seed with ram’s head shape, thin seed coat, smooth seed surface, white flowers, and lack of anthocyanin pigmentation on the stem. The plant is medium to tall in height, with large leaflets and white flowers. When compared with Desi types, the Kabuli types have higher levels of sucrose and lower levels of fiber. The Kabuli types generally have large sized seeds and receive higher market price than Desi types (Gaur et al., 2010). Chickpea seeds are eaten fresh as green vegetables, parched, fried, roasted and boiled as snack food, sweet and condiments (Dawar et al., 2007). Environmental factors such as soil moisture, sowing time, fertility and temperature and day length have strong influence during various stages of plant growth (Bull et al., 1992). The environment is changing day-by-day and this implies that it is necessary to evaluate crop genotypes at different locations to assess their performances. One approach to improve the chickpea yield is to identify stable genotypes that perform consistently better under diverse environments (Ghulam et al., 2012). The performance of a genotype is not always the same in different locations as it is influenced by environmental factors. To assess yield stability among varieties, multi-location trials with appropriate stability analysis method is required. Differences in genotype stability and adaptability to environment can be qualitatively assessed using the biplot graphical representation that scatters the genotypes according to their principal component values (Vita et al., 2010).

In Ethiopia, there is no sufficient information on the genotype by environment interaction effects on yield and yield related traits of Kabuli-type chickpea. Therefore, the current research was undertaken to examine the magnitude of environmental effect on yield and yield related traits of Kabuli-type chickpea genotypes, to study the nature and extent of genotype by environment interaction on seed yield of Kabuli -chickpea genotypes and to investigate the stability and adaptability of the genotypes under different agro-ecological condition.

MATERIALS AND METHODS

The experiment was conducted during the 2012/13 main cropping season at five locations representing various chickpea growing agro-ecologies of Ethiopia. The environments were Akaki, Chefe Donsa, Debre Zeit, Dembia and Haramaya. Thirteen (13) pipelines and four released Kabuli-type chickpea varieties were included in the study (Tables 1 and 2). The plant materials were obtained from Debre Zeit Agricultural Research Center. Planting of the genotypes was done in early mid August up to first week of September using randomized complete block design with four replications at each site under rain fed conditions. Each genotype was planted in six rows of 4 m row length and at 1.2 m width. A spacing of 30 cm row to row distance and 10 cm plant to plants were used on a plot size of 4.8 m^2. Fertilizer was not applied. Weeding and other management practice were done as required for each site. Data were recorded on days to 50% flowering, 90% physiological maturity, plant height, the number of pods per plant, the number of seeds per plant, 100-seed weight, biomass yield, grain yield, and harvest index.

Table 3. Mean sum of squares of yield and other traits from combined ANOVA of 17 Kabuli-type chickpea genotypes grown across five environments in Ethiopia.

Source	DF	DF	DM	PPP	SPP	PHT	HSW	BM	HI	YLD
E	4	3225**	12608**	7937**	0.007**	1432**	401.1**	29037069**	11097**	1504219**
G	16	242.7**	155**	653**	0.59**	268**	719.5**	662654**	258**	84562**
G X E	64	81.4**	24**	198**	0.09**	21**	7.9**	243679**	63**	28149**
Error	240	6.7	7.8	29.6	0.01	12.3	2.3	51319	24.4	8138

DF = Days to flowering, DM = days to maturity, PPP = pod per plant, SPP = seed per pod, PHT = plant height, HSW = hundred seed weight, HI = harvest index and YLD = grain yield.

Table 4. Mean grain yield (kg/ha) of 17 Kabuli-type chickpea genotypes grown at five locations in Ethiopia.

Genotype	Akaki	Chefe Donsa	Debre Zeit	Dembia	Haramaya	Mean YLD
DZ-2012-CK-0001	2933	2501	3115	1344	1628	2304
DZ-2012-CK-0002	1940	2428	2604	1446	1443	1968
DZ-2012-CK-0003	2452	2488	3304	1142	1248	2128
DZ-2012-CK-0004	2552	2518	3106	1255	795	2042
DZ-2012-CK-0005	2421	2346	2992	1655	1639	2210
DZ-2012-CK-0006	1905	2035	2552	1337	1039	1774
DZ-2012-CK-0007	1702	2265	2678	1485	1689	1774
DZ-2012-CK-0008	2315	1940	3167	1795	1460	2135
DZ-2012-CK-0009	2178	2408	2719	1617	1287	2042
DZ-2012-CK-0010	1894	2046	3310	2062	1137	2090
DZ-2012-CK-0011	1860	2120	2518	1023	1066	1718
DZ-2012-CK-0012	1775	1879	3177	1348	1935	2023
DZ-2012-CK-0013	2814	2733	2983	2675	1888	2635
Arerti (SC)	1433	3219	3560	1831	2019	2412
Ejere (SC)	1764	2477	2826	1370	1685	2025
Habru (SC)	2599	2849	3285	1419	1815	2393
Dz-10-4 (LC)	526	1814	2602	1387	1225	1510
Means	2063	2362	2970	1540	1469	2081
CV (%)	25	18	13	8	19	18
LSD	177	149	134	42	94	56

DF = Days to flowering, DM = days to maturity, PPP = pod per plant, SPP = seed per pod, PHT = plant height, HSW = hundred seed weight, HI = harvest index and YLD = grain yield, SC=standard check and LC = Local check.

Statistical analysis

Data were computed by using SAS 9.1.3 for analysis of variance, Genstat13[th] for biplot graph and Agrobase20 for stability analysis.

RESULTS AND DISCUSSION

Performance of Kabuli-type chickpea genotypes for yield

Performance trials have to be conducted in multiple environments because of the presence of GE. For the same reason, the analysis of genotype by environment data must start with the examination of the magnitude and nature of genotype by environmental interaction (Ezatollah et al., 2011). Yield and its components are polygenic traits and are strongly influenced by environment in chickpea. Significant variation was observed for grain yield in Kabuli chickpea genotypes. Similar finding were reported by Khan et al. (1987, 1988). Bartlett's test showed homogenous error variance for the grain yield and allowed to proceed further pooled analysis across environments.

The combined analysis of variance (Table 3) for grain yield exhibited significant (P≤0.01) effects of locations, genotypes and genotype by environment interaction, indicating differences in environments and the presence of genetic variability among genotypes. The presence of significant genotype by environment interaction in chickpea was reported by various authors (Singh et al., 1990; Bozoglu and Gulumser, 2000). The overall mean yield of the location varied from 1469 to 2970 kg/ha (Table 4) and thus, the five environments showed wide

Table 5. Mean values for yield related traits of Kabuli -type chickpea genotypes tested at five locations in Ethiopia (averaged over all genotypes).

Environment	DF	DM	PPP	SPP	PHT	HSW	BM	HI	YLD
Akaki	61	130	25	1.01	36	32	1071	48	2063
Chefe Donsa	56	143	30	1.01	40	29	1633	35	2362
Debre Zeit	54	108	29	1.05	45	34	1691	42	2970
Dembia	64	127	46	1.07	47	30	2519	15	1541
Haramaya	47	140	49	1.05	38	28	834	42	1469
Means	56	130	36	9.9	41	31	1550	36	2081
CV (%)	5	2	15	1.1	9	5	15	14	18
SE±	0.5	0.7	0.7	0.01	0.3	0.3	37	0.7	9.9
LSD	2	2	3	0.1	2.2	1	141	3.1	56

YLD = Grain yield, DF = days to flower, DM = days to mature, PPP= pod per plant, SPP= seed per pod, PHT=plant height, BM= biomass yield, HI= harvest index, HSW= hundred seed weight.

variation in yield potential. The highest mean grain yield was obtained at Debre Zeit (2970 kg/ha) and the lowest was from Haramaya (1469 kg/ha). The possible reason was that late planting was done at Haramaya and due to this moisture stress occurred at vegetative and pod setting stage while relatively sufficient moisture was available at Debre Zeit. Genotypic means across the locations indicated that maximum mean grain yield across all the five locations in one year were obtained from DZ-2012-CK-0013 genotype (2635 kg/ha) and the minimum was from the local variety (1510 kg/ha). Genotype by environment interaction causes differences in yield rank of genotypes in different locations; thus, it becomes important for the chickpea breeders in terms of selection efficiency and genotype suggestions for different locations.

Genotypes showed inconsistent performances across all environments. Genotypes expressed their genetic potential differently in different environments (Table 4). At Akaki, Chefe Donsa, Debre Zeit, Dembia and Haramaya, the top performing genotypes were DZ-2012-CK-0001 (2933 kg/ha), Arerti (3219 kg/ha), Arerti (3560 kg/ha) DZ-2012-CK-0013 (2675 kg/ha) and DZ-2012-CK-0013 (2019 kg/ha), respectively. The genotype DZ-2012-CK-0013 tops performing at Dembia and Haramaya with the average mean yield of 2675 and 2019 kg/ha, respectively. The mean grain yield averaged over environments and genotypes were 2080 kg/ha (Tables 3 and 4). In summary the relative ranking of genotypes at all the five environments were different and CV values of genotype ranged from 2.1 to 18.1% (Table 6).

Performance of Kabuli-type genotype for yield related traits

From the combined analysis of variance, the mean squares due to genotypes, environments and genotype by environment interaction were highly significant for the traits, days to flowering, days to maturity, plant height, number of pods per plant, hundred seed weight, above ground dry biomass and harvest index. However, there were no-significant effects of all these three source of variation on the number of seeds per pod (Table 3). The separate analysis of variance for all yield related traits, except for number of seed per pod at each location exhibited highly significant (*P≤0.01*) differences among Kabuli-type chickpea genotypes for the days to flowering, days to maturity, number of pods per plant, plant height, hundred seed weight, above ground dry biomass and harvest index at all locations. Similar results were reported by different researchers who worked on chickpea (Singh et al., 1990; Bozoglu and Gulumser, 2000 and Valimohammadi et al., 2007). The responses of genotypes in terms of all yield related traits were different both within and across locations. This indicated that the efficiency of a breeding program aimed at yield improvement is impaired due to genotype by environment interaction, which complicates the process of crop variety development especially when varieties are selected in one environment and used in others (Ahmad et al., 2011).

Days to flowering and maturity

The result reveals significant effects not only for genotypes but also for locations and genotype by environment interaction, variability in experimental material as well as difference in the environmental conditions (Table 3). Early flowering and early maturing genotypes were observed at Haramaya and Debre Zeit (47 and 108 days) and at the same time late flowering and mature genotypes were noted at Dembia and Chefe Donsa (64 and143 days), respectively (Table 5). The probable reason was due to high temperature and early cessation of rain at Haramaya and, relatively long rain season and low temperature at Chefe Donsa. Ejere and

Table 6. Mean performance for yield related traits of 17 Kabuli-type chickpea genotypes grown at five environments.

Genotype	DF	DM	PPP	SPP	PHT	HSW	BM	HI
DZ-2012-CK-0001	58	129	34	1.1	39	31	1775	37
DZ-2012-CK-0002	57	132	34	1	39	33	1585	34
DZ-2012-CK-0003	58	131	35	1	41	35	1640	32
DZ-2012-CK-0004	57	129	33	1	38	30	1487	37
DZ-2012-CK-0005	59	132	30	1	44	34	1540	37
DZ-2012-CK-0006	58	134	28	1	40	37	1655	31
DZ-2012-CK-0007	57	131	32	1	46	30	1585	33
DZ-2012-CK-0008	60	133	33	1	43	36	1775	33
DZ-2012-CK-0009	59	130	33	1	49	31	1572	36
DZ-2012-CK-0010	51	131	41	1	43	34	1420	39
DZ-2012-CK-0011	57	131	32	1	36	30	1335	34
DZ-2012-CK-0012	52	130	34	1	46	31	1635	35
DZ-2012-CK-0013	58	131	36	1	41	33	1810	38
Arerti (SC)	57	127	43	1	35	24	1620	41
Ejere(SC)	49	124	37	1	38	33	1438	41
Habru (SC)	49	124	39	1	40	30	1395	43
Dz-10-4(LC)	57	126	52	1.7	39	17	1078	39
Means	56	130	36	1.1	41	31	1550	37
CV (%)	5	2	15	18.1	9	5	15	14
SE±	0.5	1	1	0.01	0.4	0.3	37	0.7
LSD	2	2	3	0.1	2	1	141	3.1

DF = Days to flower, DM = days to mature, PPP = pod per plant, SPP = seed per pod, PHT = plant height, BM = biomass yield, HI= harvest index, HSW = hundred seed weight. SC = standard check; LC = local check

Habru were both early flowering and early maturing varieties while the genotypes DZ-2012-CK-0008(60) and DZ-2012-CK-0006 (134) were late flowering and late maturing (Table 6).

Number of pods per plant

Number of pods per plant is an important selection criterion for the development of high yielding genotypes and is strongly influenced by environment in chickpea (Malik et al., 1988). Marked variation was observed in the performance of genotypes over the five locations (Table 3). Number of pods per plant was highest at Haramaya (49) and least at Akaki (25) (Table 5). The genotypes mean values for number of pods per plant varied from 28 for DZ-2012-CK-0006 to 52 DZ-10-4. The highest mean number of pods per plant was recorded for genotypes Dz-10-4 (52) followed by Arerti, DZ-2012-CK-0010 (43), Habru (39) (Table 6). These results are consistent with the findings of Singh and Bains (1984) and Malik et al. (1988). These results indicate variability for number of pods per plant and its sensitiveness to environmental fluctuations.

Plant height (cm)

Significant effects were observed not only for genotypes but also for locations and genotype by environment interaction, reflecting genetic variability in experimental material as well as difference in the environmental conditions (Table 3). Averaged over all genotypes the highest plant height was recorded at Dembia (47 cm) and the shortest was Akaki (36 cm) (Table 5). Plant height was sensitive to environmental fluctuations and it indicated that the relative performance of genotypes was markedly inconsistent over the locations. Averaged over all locations the shortest genotype was Arerti (35 cm) and the longest genotype was DZ-2012-CK-0009 (49 cm) (Table 6). These results are consistent with the findings in chickpea of Malik et al. (1988) who also found high magnitude of genotype by environment interaction.

100-grain weight (g)

Statistically significant variance was observed for genotypes, location and genotype and environment interaction (Table 3). Over all genotypes hundred seed weight was highest for Debre Zeit (34.2 g) and lowest for Haramaya (28.3 g) (Table 5). In addition, the relative performance of genotypes is quite inconsistent across the environments. The genotype with the smallest 100-grain weight was DZ-10-4 (17 g) and the one with the highest was DZ-2012-CK-0006 (37 g) (Table 6). The significant pooled deviation for 100-grain weight suggested that these genotypes differ considerably with respect to their suitability for this character. The present results are in agreement with the findings of Singh and Singh (1974) and Sanghi and Kandakar (2001).

Above-ground dry biomass

Statistically highly significant variance was observed for genotypes, locations and genotype and locations interaction (Table 3). Averaged across all genotypes above ground dry biomass was highest for Dembia (2519 g) and lowest for Haramaya (834 g) (Table 5).

Harvest index

Statistically highly significant variance was observed for genotypes, locations and genotype and locations interaction (Table 3). Averaged over all genotypes, harvest index was highest for Akaki (47.9%) and least for Dembia (15.1%) (Table 5). Harvest index ranged from (30.7%) for DZ-2012-CK-0006 to (43.7%) for Habru (Table 6). The presence of genetic variation on agronomic traits of Kabuli-type chickpea was similarly reported by Singh et al. (1990) and Bozoglu and Gulumser (2000).

Stability analysis

Wricke's ecovalence analysis

Wricke's ecovalence (*Wi*) was calculated for each of the 17 Kabuli-type chickpea genotypes evaluated at five diverse locations for one year in the major chickpea growing regions of Ethiopia (Table 7). The genotypes with the lowest ecovalence contributed the least to the genotype by environment interaction and are therefore more stable. Accordingly, DZ-2012-CK-0006, DZ-2012-CK-0011, DZ-2012-CK-0005, DZ-2012-CK-0002, DZ-2012-CK-0009, Ejere and DZ-2012-CK-0007 were the most stable genotypes that for grain yield ranked 15th, 16th, 5th, 13th, 10th, 11th and 14th, respectively. Although, the most unstable genotypes were Arerti, DZ-10-4, DZ-2012-CK-0004, DZ-2012-CK-0013, DZ-2012-CK-0010, DZ-2012-CK-0001, DZ-2012-CK-0012, DZ-2012-CK-0003; that for grain yield ranked 2nd, 17th, 9th, 1st, 8th, 4th, 12th and 7th, respectively. The results indicate that high yielders have high ecovalence and *vice versa*. As a result, genotype recommendation for general adaptability would be difficult. According to Asrat et al. (2008), genotypes with high ecovalence mean and large estimated values are suitable for high input environments.

Table 7. Wrickes ecovalence value for 17 Kabuli-type chickpea genotypes at five environments.

Genotype	Wi	Rank	Mean yield	Rank
DZ-2012-CK-0001	35315	6	2304	4
DZ-2012-CK-0002	5784	14	1968	13
DZ-2012-CK-0003	27560	8	2128	7
DZ-2012-CK-0004	46768	3	2042	9
DZ-2012-CK-0005	5005	15	2210	5
DZ-2012-CK-0006	3516	17	1774	15
DZ-2012-CK-0007	12104	11	1962	14
DZ-2012-CK-0008	19016	9	2135	6
DZ-2012-CK-0009	6341	13	2042	10
DZ-2012-CK-0010	36075	5	2090	8
DZ-2012-CK-0011	4269	16	1718	16
DZ-2012-CK-0012	34299	7	2023	12
DZ-2012-CK-0013	40149	4	2635	1
Arerti (SC)	75764	1	2412	2
Ejere (SC)	10587	12	2025	11
Habru (SC)	15586	10	2393	3
Dz-10-4 (LC)	72254	2	1510	17

SC = Standard check; LC = Local check

Table 8. Sum of square and mean sum of squares from the analysis of variance for linear regressions of Kabuli-type chickpea genotypes means on environmental index according to Eberhart and Russell's joint regression model (1966).

Source of variation	Df	SS	MS
Total	339	2292863	
Genotype	16	338251	21141**
Env. + in Gen + Env.	68	1954612	28744
Env. in linear	1	1504219	1504219**
Gen x Env. (linear)	16	77859	4866
Pooled deviation	51	372533	7305**
Residual	255	540506	2119

**Significant at P≤0.01; Grand mean = 499.365, R-squared = 0.8094, C.V. = 18.44%.

Eberhart and Russell's joint regression stability analysis

The mean square for genotype by environment significant was (*p≤0.01*) for grain yield (Table 3). This permitted the partitioning of genotype by environment effects in environment linear, G x E (linear) interaction effects (sum squares due to regression (bi) and unexplained deviation from linear regression (pooled deviation mean squares (S^2di). The genotype by environment (linear) interaction was not significant indicating that the stability parameter 'bi' estimated by linear response to change in environment was the same for all genotypes or genotypes have the same slope (Table 8). Similar results were obtained in bean genotypes tested (Firew, 2003; Setegn and Habtu, 2003) in different part of Ethiopia and in Brazil (Ferreira et al., 2006). Our results reveal that the

Table 9. Mean yield, regression coefficients (*b*), coefficients of determination and deviation from regression (S^2di) of Kabuli genotype.

Genotype	b_i	r_i^2	S^2d_i	Mean yield	Rank
DZ-2012-CK-0001	1.68	1.01	9329	2304	4
DZ-2012-CK-0002	1.43	0.99	807	1968	13
DZ-2012-CK-0003	1.68	1.00	1307	2128	7
DZ-2012-CK-0004	1.53	1.01	6940	2042	9
DZ-2012-CK-0005	1.68	0.99	761	2210	5
DZ-2012-CK-0006	1.36	0.99	1043	1774	15
DZ-2012-CK-0007	1.52	1.00	0.002	1962	14
DZ-2012-CK-0008	1.78	1.00	4139	2135	6
DZ-2012-CK-0009	1.49	1.00	260	2042	10
DZ-2012-CK-0010	1.82	1.01	9665	2090	8
DZ-2012-CK-0011	1.30	0.99	742	1718	16
DZ-2012-CK-0012	1.80	1.01	9112	2023	12
DZ-2012-CK-0013	1.82	1.00	4351	2635	1
Arerti (SC)	1.96	1.03	22135	2412	2
Ejere (SC)	1.56	1.00	1196	2025	11
Habru (SC)	1.77	1.00	2230	2393	3
Dz-10-4 (LC)	1.43	1.03	21350	1510	17

bi = Regression coefficients, r^2i. coefficients of determination, S^2di. deviation from regression. SC = Standard check; LC = Local check.

genotype by environment interaction was not a linear function of environment indices. The variation among the genotypes and for genotype by environment interaction were significant effects which means that genotypes exhibited different performances in different environments which is due to their different genetic makeup or the variation due to the environments or both. The mean sums of squares due to pooled deviation from regression were significant ($p \leq 0.01$) for grain yield indicating the importance of non linear genotype by environment. The most stable genotype with the lowest S^2di values were DZ-2012-CK-0007($s^2di=0.002$), DZ-2012-CK-0009, DZ-2012-CK-0011, DZ-2012-CK-0005 and DZ-10-2012-CK-0002 in decreasing order. The most unstable genotype with the highest S^2di values were Arertie, DZ-10-4, DZ-2012-CK-0010, DZ-2012-CK-0001, DZ-2012-CK-0012, DZ-2012-CK-0004, DZ-2012-CK-0013 and DZ-2012-CK-0008 which ranked 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th, respectively. Therefore, these genotypes were best fit for specific adaptation in favorable environments where there were high levels inputs. If the mean yield, regression coefficient value (*bi*) and the deviation from the regression (S^2di) are considered together simultaneously, there was no stable genotype. All genotypes had regression coefficients (bi) greater than one (that is, below average stability and significant deviation from regression). Therefore, these genotypes were specifically adapted to favorable environments (Table 9).

AMMI analysis of 17 Kabuli-type chickpea genotypes tested at five environments

The AMMI analysis of variance of grain yield of 17 Kabuli-type chickpea genotypes tested in five environments is presented on Table 7. The analysis revealed that Kabuli-type chickpea genotypes were significantly (P≤0.01) affected by environments (E), genotypes (G) and genotype by environment interaction. The main effects of E and G accounted for 53.1 and 11.9%, respectively, and G X E interaction accounted for 15.9% of the total variation of Genotype by environment data for grain yield (Table 10). The first two principal components (PC1 and PC2), which were used to create a two-dimensional biplot, explained 52.5 and 21.95% of AMMI sum of squares, respectively. According to the AMMI model, the genotypes which are characterized by means greater than grand mean and the IPCA score nearly zero are considered as generally adaptable to all environment (Ezatollah et al., 2013). However, the genotype with high mean performance and with large value of IPCA score are consider as having specific adaptability to the environments. The large sum of squares for environments showed that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. This is in synchronization with the findings of Singh et al. (1990), Yan (2002) and Yan and Tinker (2006) in chickpea

Table 10. Additive Main effects and Multiplicative interaction (AMMI) analysis of variance for grain yield (kg/ha) of the 17 Kabuli-type genotypes tested across five locations.

Source	Df	Sum of squares	Mean squares	% Explained
Total	339	11333475	33432	
Environment (L)	4	6016879	1504220**	53.1
Genotype (G)	16	1353003	84563**	11.9
G × L	64	1801570	28150**	15.9
IPC1	19	945954	49787**	52.5
IPC2	17	395464	23263**	21.9
IPCA3	15	237463	15831*	13.2
Residuals	13	222688	17130	

*,**Significant at P≤0.05 and P≤0.01, respectively.

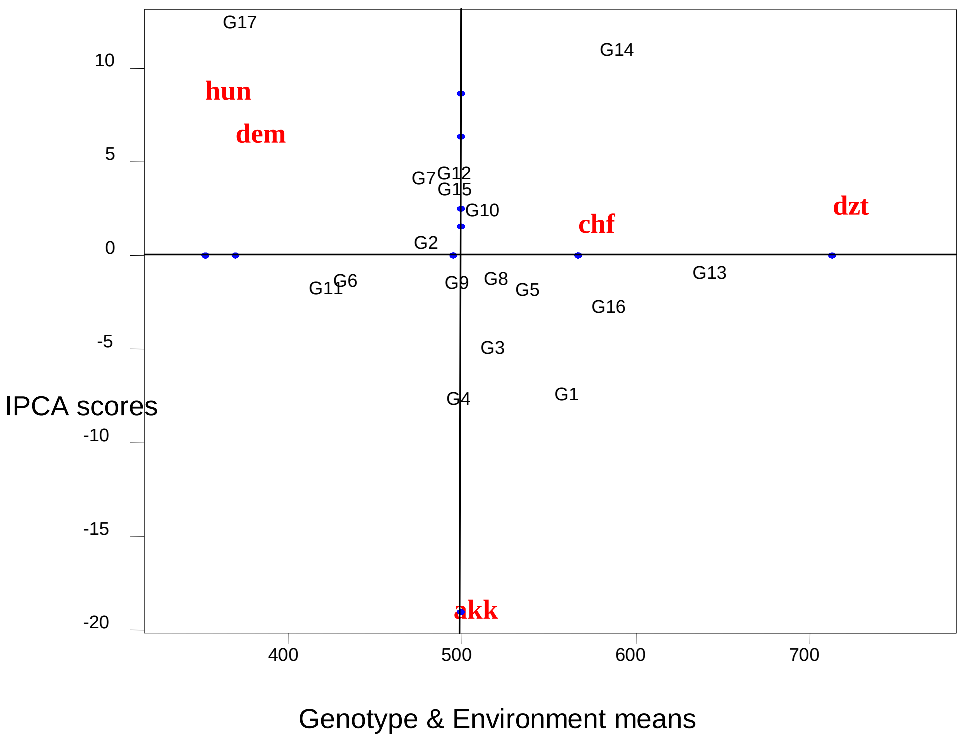

Figure 1. AMMI biplot analysis of IPCA scores genotype and environment means for Kabuli-type genotypes.

production. This result also indicates the considerable influence of environments on the yield performance of Kabuli-type chickpea genotypes in Ethiopia. The magnitude of the genotype by environment sum of squares was more than two times that for genotypes, indicating that there were considerable differential genotype responses across environments.

The AMMI I, biplot for grain yield of the 17 Kabuli-type chickpea genotypes at five environmental conditions is shown in Figure 1. The main effects (genotypes and environments) accounted for 65.02% of the total variation and IPCA 1 accounted for 52.5% of the total variation due to genotype by environment interaction alone. Environments showed high variation in both main effects and interactions (IPCA1) (Figure 1). Chefe Donsa and Debre Zeit are the most favorable environments; Haramaya and Dembia are the least favorable environments, while Akaki is the average environment. Environments are classified into three main groups based on their IPCA 1 scores Haramaya and Dembia are in quadrant I and have got large positive IPCA1 scores, which interact positively with genotypes that have positive

IPCA1 scores and negatively with those genotypes having negative IPCA1 scores. Chefe Donsa and Debre Zeit in quadrants II and have got small positive IPCA1 scores, which interact positively with genotypes that have positive IPCA1 scores and negatively with those genotypes having negative IPCA1 scores; Akaki in quadrant III and has got large negative IPCA1 scores which interact negatively with genotypes having negative IPCA1 scores and positively with genotypes having positive IPCA1 scores; and Akaki is in quadrant III and has got large negative IPCA1 scores which interacts negatively with genotypes that have negative IPCA1 scores and positively with those genotypes having positive IPCA1 scores (Table 10). The environments can be sub-grouped according to their average yield over the genotypes. According to environmental IPCA1 scores, Akaki, Chefe Donsa and Debre Zeit were more stable and had lower genotype by environment interaction, and had high yield performance. On the other hand, the highest IPCA1 scores belonged to Haramaya and Dembia, but they had low yield performance. According to IPCA1, environment Debre Zeit was an ideal environment for selecting genotypes with specific adaptation to high input conditions.

The IPCA 1 and IPCA 2 components were significant ($P \leq 0.01$) and accounted for 52.5 and 21.95% of the total G X E interaction sum of squares, respectively. The two of them explained more than 74.45% of the total G X E interaction variation (Table 10). This indicates that the AMMI biplot model is the best fit for this data set, which is in agreement with other studies (Zobel et al., 1988; Yan and Hunt, 1988). In Figure 1, the genotypes and locations that are located far away from the origin are more responsive. Haramaya, Debre Zeit, Dembia and Chefe Donsa are the most differentiating environments, while Akaki is more responsive environment than the other environments since it is far away from the origin. The genotypes DZ-2012-CK-0003, DZ-2012-CK-0008 and DZ-2012-CK-0013 were the most stable as well as productive. DZ-2012-CK-0005, Habru and DZ-2012-CK-0009 were stable with intermediate productivity. DZ-10-4 and Arerti are less responsive. Genotypes and environments that fall into the same sector interact positively; negatively if they fall into opposite sectors (Osiru et al., 2009). A genotype showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of the specific environment. If they fall into adjacent sectors, interaction is somewhat more complex. In this case, the best genotype with respect to Akaki site are DZ-2012-CK-0003, DZ-2012-CK-0005, DZ-2012-CK-0013, DZ-2012-CK-0001, DZ-2012-CK-0008 and Habru with respect to Chefe Donsa and Debre Zeit they were DZ-2012-CK-0010 and Arerti and DZ-10-4, DZ-2012-CK-0002, DZ-2012-CK-0012 and Ejere were the best genotype for environments of Dembia and Haramaya. DZ-2012-CK-0001=G1, DZ-2012-CK-0002=G2, DZ-2012-CK-0003=G3, DZ-2012-CK-0004=G4, DZ-2012-CK-0005=G5, DZ-2012-CK-0006=G6, DZ-2012-CK-0007=G7, DZ-2012-CK-0008=G8, DZ-2012-CK-0009=G9, DZ-2012-CK-0010=G10, DZ-2012-CK-0011=G11, DZ-2012-CK-0012=G12, DZ-2012-CK-0013=G13, Arerti=G14, Ejere=G15, Habru=16 and Dz-10-4=G17, Chf= Chefe Donsa, Akk=Akaki, Dzt=Debre Zeit=Dem=Dembia and Hun=Haramaya.

AMMI stability value

According to the ASV ranking, the most stable genotypes were DZ-2012-CK-0002, DZ-2012-CK-0006 and DZ-2012-CK-0009. DZ-2012-CK-0013 and Arerti which were the first and second highest yielders based on the mean yield values (Table 11). However, DZ-2012-CK-0013 which gave the highest mean yield, ranked 12th for the ASV. The most unstable genotypes according to the ASV were DZ-10-4 and DZ-2012-CK-0004 (Table 11).

Cluster analysis of genotypes and environments

Cluster analysis was performed to study the patterns of groupings of genotypes and environments. The dendrograms (Figures 2 and 3) were generated from SAS clustering method of genotypes and environments based on Euclidean distances using AMMI adjusted mean yields of genotypes and environments, respectively. Clustering of genotypes at a cut-off value of zero produced five clusters. Cluster one consisted of 11 genotypes (DZ-2012-CK-0001, DZ-2012-CK-0002, DZ-2012-CK-0003, DZ-2012-CK-0004, DZ-2012-CK-0005, DZ-2012-CK-0007, DZ-2012-CK-0008, DZ-2012-CK-0009, DZ-2012-CK-0010, DZ-2012-CK-0012 and Ejeri). Cluster two consisted of two genotypes (Arerti and Habru). The third cluster also consisted of two genotypes (DZ-2012-CK-0006 and DZ-2012-CK-0011). The fourth group consisted of only one genotype (DZ-2012-CK-0013), and this genotype is the highest yielder of all the 17 Kabuli-type chickpea genotype. The last group included only one genotype local variety which was the lowest yielder of all the 17 genotypes. Cluster analysis of environments at cut-off point 1.0 produced three clusters, two of which consisted of two environments each and the third cluster consisted only one environment. Chefe Donsa and Debre Zeit were in the first group. The second cluster included only Dembia and the third cluster consisted of Akaki and Haramaya.

Conflict of interests

The authors did not declare any conflict of interest.

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Table 11. Yield and parametric stability statistics for grain yield on 17 Kabuli genotypes grown in five environments.

Genotype	IPCA1	IPCA2	ASV	Rank	Yield
DZ-2012-CK-0001	-7.83	2.64	11.81	14	2304
DZ-2012-CK-0002	0.23	0.32	0.48	1	1968
DZ-2012-CK-0003	-5.34	5.17	9.74	13	2128
DZ-2012-CK-0004	-8.08	2.15	12.67	15	2042
DZ-2012-CK-0005	-2.27	-1.39	3.77	4	2210
DZ-2012-CK-0006	-1.76	-2.18	3.49	2	1774
DZ-2012-CK-0007	3.71	0.07	5.74	7	1962
DZ-2012-CK-0008	-1.69	-5.32	5.93	9	2135
DZ-2012-CK-0009	-1.89	-2.01	3.55	3	2042
DZ-2012-CK-0010	1.98	-7.25	7.87	11	2090
DZ-2012-CK-0011	-2.18	1.85	3.84	5	1717
DZ-2012-CK-0012	3.97	1.23	4.16	6	2023
DZ-2012-CK0013	-1.35	-9.45	9.68	12	2635
Arerti (SC)	10.55	6.79	17.67	16	2412
Ejere (SC)	3.11	3.16	5.75	8	2025
Habru (SC)	-3.18	5.66	7.49	10	2393
Dz-10-4 (LC)	12.04	-1.43	18.67	17	1510

Wi2, Wricke´s ecovalence; S^2di, deviation from regression; bi, regression coefficient; r^2i, coefficient of determination; IPCA1 and IPCA2, interaction principal components axes 1 and 2, respectively; ASV, AMMI stability value; SC, standard check; LC, local check.

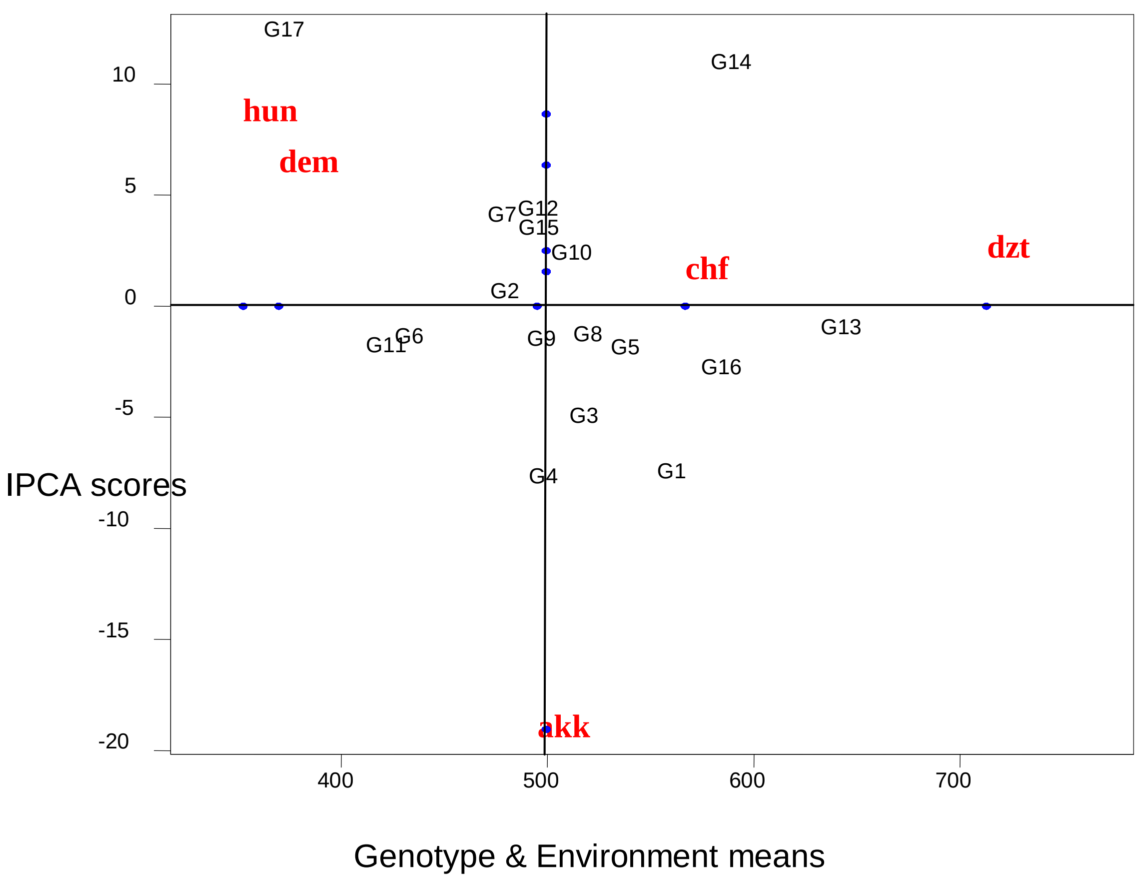

Figure 1. AMMI biplot analysis of IPCA scores genotype and environment means for Kabuli-type genotypes.

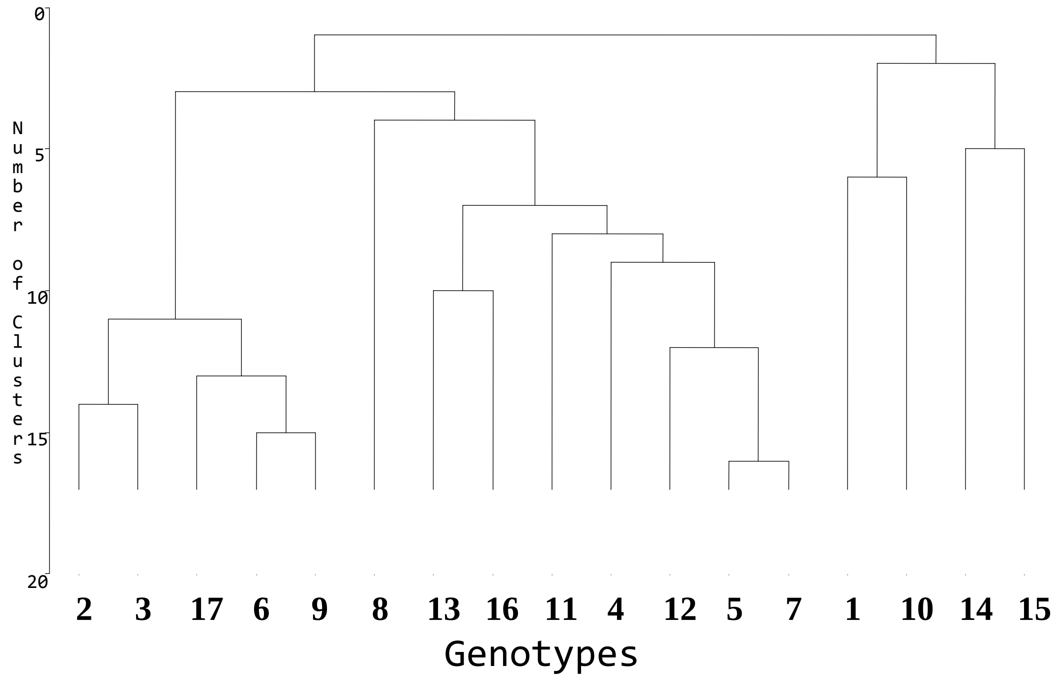

Figure 2. Dendrogram illustrating cluster analysis of Kabuli-type chickpea genotypes. DZ-2012-CK-0001=1, DZ-2012-CK-0002=2, DZ-2012-CK-0003=3 DZ-2012-CK-0004=4, DZ-2012-CK-0005=5, DZ-2012-CK-0006=6, DZ-2012-CK-0007=7, DZ-2012-CK-0008=8, DZ-2012-CK-0009=9, DZ-2012-CK-0010=10, DZ-2012-CK-0011=11, DZ-2012-CK-0012=12, DZ-2012-CK-0013=13, Arerti=14, Ejere=15, Habru=16 and Local variety=17.

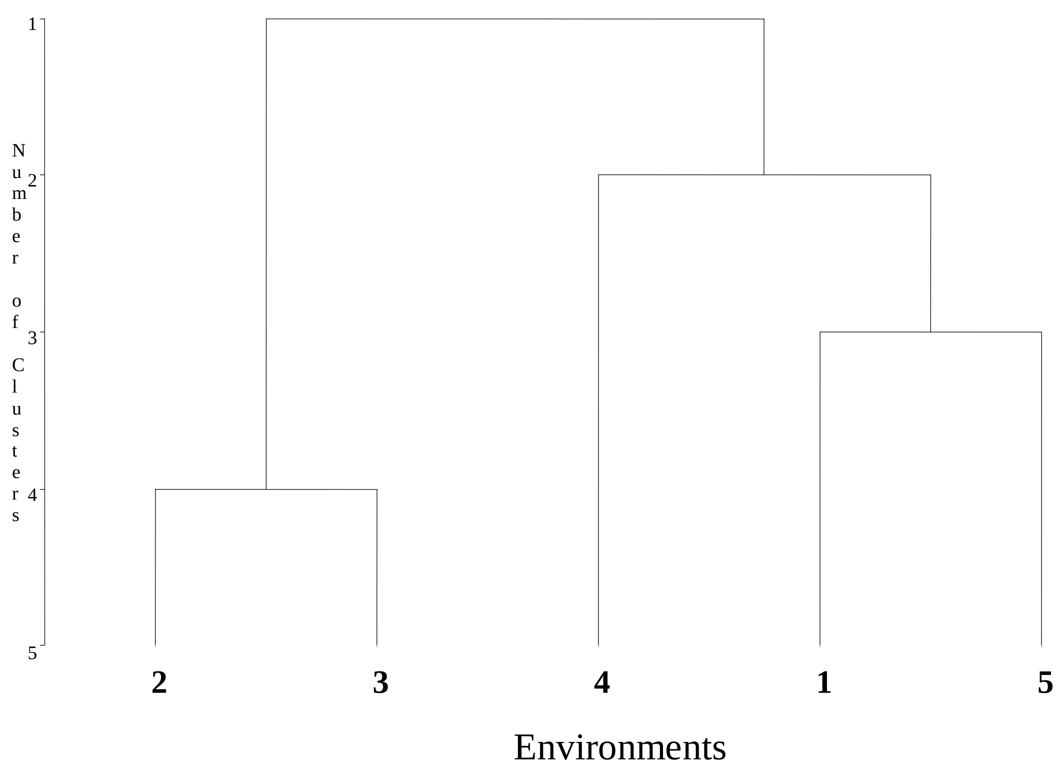

Figure 3. Dendrogram illustrating the clustering of five environments for Kabuli-type chickpea genotypes. Akaki=1, Chefe Donsa=2, Debre Zeit=3, Dembia=4 and Haramaya=5.

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