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Assessment of Genetic Improvement in Grain Yield Potential and Related Traits of Kabuli Type Chickpea (*Cicer arietinum* L.) Varieties in Ethiopia (1974-2009)

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Abstract

Kabuli type chickpea is the most important commercial crop in Ethiopia and worldwide. A set of experiment was conducted to estimate the progress made in improving grain yield potential of Kabuli type chickpea varieties and changes in agromorphological traits associated with genetic yield potential. The varieties were laid down in a Randomized Complete Block Design with three replications. The annual rate of increase in yield potential of Kabuli type chickpea was estimated from linear regression of mean grain yields of varieties on year of release was 8.42 kg $ha^{-1}yr^{-1}$ but this increment was not significantly different from zero. This revealed that chickpea breeders have made little/small efforts over the last 35 years to improve the yield of Kabuli type chickpea in Ethiopia. From the linear regression of hundred seed weight (HSW) against the years of release indicated that the annual rate of genetic gain was 1.00 g HSW^{-1} (8.96%) yr^{-1}, reflected that a significant increase was recorded for this trait for the last 35 years of Kabuli type chickpea improvement program in Ethiopia. Hence, better genetic improvement was obtained from breeding for HSW than it was from breeding for grain yield in Kabuli type. In contrast, significant negative trend was observed in number of pods $plant^{-1}$, seeds per pod^{-1} and seeds $plant^{-1}$. The correlation coefficients showed that grain yield was significantly and positively correlated with primary branches $plant^{-1}$, biomass yield and with all productivity traits. However, HSW which is the economical trait in Kabuli type chickpea showed significant negative association with secondary branches $plant^{-1}$, pods $plant^{-1}$, seeds pod^{-1} and seeds $plant^{-1}$. Stepwise regression analysis revealed that most of the variation in grain yield was caused by biomass yield and harvest index.

Keywords: Kabuli type chickpea; Genetic improvement; Harvest index; HSW; Grain yield; Yield components

Introduction

Chickpea (*Cicer arietinum* L.) is one of the principal food legumes in Ethiopia and it covers about 213,187 hectares of land and 2,846,398 quintals of chickpea is produced per annum with average productivity of 1.34 tons per hectare [1]. It, therefore, ranks third in production next to faba bean and haricot bean, but it ranks second in productivity per unit of area next to haricot bean. This clearly indicates the importance of chickpea in Ethiopian agriculture. Ethiopia is the largest producer of chickpea in Africa, accounting for about 46% of the continent's production during 1994 to 2006. It is also the seventh largest producer worldwide and contributes about 2% of the total world chickpea production [2].

According to Bekele [3], Kabuli type chick pea varieties are the most important crop in terms of local and export markets due to their large-seeded type. Therefore, there is a higher economic incentive for farmers to shift from Desi to Kabuli production due to its high price in world market. In Ethiopia, seeds are consumed raw, roasted or in 'wot'. Sometimes, the flour is mixed with other crops for preparing injera and also unleavened bread. Green pods and tender shoots are used as a vegetable. The roasted and salted chickpea is used as snack. It can also be mixed with cereals and root crops as a protein supplement in preparing "fafa" [4]. It is also an important legume crop used in rotation with several cereals like tef or wheat on heavy soils and maintains soil fertility through nitrogen fixation [5,6]. However, both productivity and quality of Ethiopian chickpeas have so far remained threateningly suboptimal due mainly to traditional and inadequate agronomic management practices, low yield potentials of the types under widespread cultivation and ravages of various biotic and abiotic stresses.

More than nine Desi type improved chickpea varieties along with their management practices have been developed and released through the national agricultural research systems in Ethiopia since the inception of chickpea improvement program at Debre Zeit Agricultural Research Center (DZARC) about four decades ago [7]. As can been seen from the annual production statistics above, the national average yield of chickpea is very low (about one tone per hectare) [1]. On the contrary, in areas where improved chickpea technologies were adopted and used, yield levels of up to five tons per hectare have been achieved [7]. This huge productivity gap warrants wider dissemination of the improved chickpea technologies in order substantially boost up the overall productivity and production in the country.

Information on genetic progress achieved over time from a breeding program is absolutely essential to develop effective and efficient breeding strategies by assessing the efficiency of past improvement works in genetic yield potential and suggest on future selection direction to facilitate further improvement [8-11]. Progress made in genetic yield potential and associated traits produced by different crops improvement program and the benefits obtained have been evaluated and documented

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in different countries concluded that genetic improvement in those crops have produced modern cultivars with improved yield potential [11-17]. This is also true for some crops in Ethiopia [18-24].

However; despite considerable effort and devotion of resources to Kabuli type chickpea improvement, there has been no work conducted in Ethiopia and worldwide to evaluate and document the progress made in improving the genetic yield potential and associated traits of Kabuli type chickpea varieties from different years in a common environment. Therefore, there is a need to quantify genetic progress in Kabuli type chickpea to design effective and efficient breeding strategy for the future. Hence, this research was initiated with the following objectives:

- To estimate the progress made in improving genetic yield potential of Kabuli type chickpea varieties.
- To assess changes in agro-morphological characters and thereby to identify their association with genetic improvement of Kabuli type chickpea varieties.

Materials and Methods

The experiment was conducted during the main cropping season of 2010 under rain fed condition in the experimental fields of Debre Zeit Agricultural Research Center (DZARC) and Akaki substation. DZARC is located at 08°44'N, 38°58'E and an altitude of 1900 masl. It's mean annual rainfall of 851 mm and mean maximum and minimum temperature of 28.3°C and 8.9°C respectively. Akaki is also situated at 08°52'N and 38°47'E with an altitude of 2200 masl and characterized by long term average annual rainfall of 1025 mm and mean maximum and minimum temperature of 26.5°C and 7.0°C respectively.

The study consisted of nine Kabuli type chickpea varieties released since 1974. The varieties were planted in a Randomized Complete Block Design (RCBD) with three replications at each experimental location. The experimental plot area was 4.8 m^2 having 4 rows each 4 m long and 1.2 m width. Spacing of 0.30 m between rows and 0.10 m between plants were used; the two middle rows with an area of 2.4 m^2 used for data collection. The spacing between plots and blocks were 0.40 m and 1.0 m respectively. Field management and protection practices were applied based on research recommendation for each respective location.

Data on yield and yield related traits were collected on plot and plant basis, such as phenological traits [days to 50% flowering (DF), days to 90% physiological maturity (DM), grain filling period (GFP)], grain yield, biomass yield, harvest index, yield attributes (plant height, number of primary branches per plant, number of secondary branches per plant, number of pods per plant, number of seeds per pod, number of seeds per plant, grain yield per plant, hundred seed weight and productivity traits (biomass production rate, seed growth rate and, grain yield per day).

All measured parameters were subjected to analysis of variance (ANOVA) using PROC ANOVA of SAS software version 9.0 [25] to assess the differences among the tested varieties. The homogeneity of error mean squares between the two locations were tested by F test on variance ratio and combined analyses of variance were performed for the traits whose error mean squares were homogenous using PROC GLM procedure of SAS. Number of pods plant^{-1}, number of seeds plant^{-1}, grain yield plant^{-1}, biomass yield hectare^{-1}, biomass production rate, seed growth rate and grain yield day^{-1} were transformed and their error variances were homogenized by log transformation according to Gomez [26]. Mean separation was carried out using Duncan's Multiple Range Test (DMRT).

The breeding effect was estimated as a genetic gain for grain yield and associated traits in chickpea improvement by regressing mean of each character for each variety against the year of release of that variety using PROC REG procedure. The coefficient of linear regression gives the estimate of genetic gain in kg ha^{-1}yr^{-1} or in % per year [27]. For this study, the year of release was expressed as the number of years since 1974; the year when the first Kabuli type chickpea variety was released. The relative annual gain achieved over the last 35 years (1974-2009) was determined as a ratio of genetic gain to the corresponding mean value of oldest variety and expressed as percentage.

To compute Pearson product moment correlation coefficients among all characters using means of each variety, PROC CORR in SAS was used. Stepwise regression analysis was carried out on the varietal mean using PROC STEPWISE in SAS to determine those traits that contributed much for yield variation among varieties.

Results and Discussion

Grain yield potential

Combined analysis of variance across the two locations showed highly significant ($p \leq 0.01$) difference in grain yield among varieties while the effect of location on grain yield was non-significant (Table 1). The location × variety interaction effect was also non-significant for this trait. The grain yield performance of all Kabuli type chickpea varieties averaged over locations was 2018.25 kg ha^{-1}, which ranged from 1451.4 kg ha^{-1} for the variety Monino (recently released variety) to 2789.6 kg ha^{-1} for the variety Arerti (Table 2). The most recently released variety Monino, showed lower grain yield than all varieties represented in the current study. It showed lower grain yield than the first old variety (DZ-10-4) by 76.00 kg ha^{-1} (5%) (Table 3). This clearly indicated that grain yield of Kabuli type chickpea was not improved consistently as per the year of release.

The mean grain yield of varieties released in 1970s, 1990s and 2000s were 1527.40, 2398.75 and 1973.23 kg ha^{-1} respectively. These showed that an increase of 871.35 (57.05%) and 445.83 kg ha^{-1} (29.19%) over the first released variety, respectively. The average grain yield of those varieties which were released in 2000s exceeded that of the first variety but it was smaller than the yield of the variety released in 1990s by 425.52 kg ha^{-1} (17.74%) (Table 4). This clearly indicated that, in Ethiopia, the variety which was released in 1999 (Arerti) was highly productive because of its high yielding potential and is still under cultivation and not yet substituted by other Kabuli type chickpea varieties, but the criteria for releasing other variety were seed size, seed color and other quality parameters [28]. That is why the recently low yielding variety Monino was released. As indicated in Table 5, variety Monino was by far higher in seed size than the first older variety (DZ-10-4). It exceeded the older variety by 51.10 g (456.25%) in hundred seed weight and by 36.60 g (142.41%) in hundred seed weight over the higher yielder variety (Arerti). To this effect, it seems to strategically be advisable that hybridization efforts in the future should give attention to building on the short coming of low yielding modern varieties like Monino with high yielding varieties like Arerti for simultaneous improvement of grain yield and hundred seed weight. Similarly, Pereira [29] reported that there was lack of increase in yield potential during the period 1930-1970 in sunflower. According to these authors, the importance of selection for disease tolerance and grain quality plus a reduced genetic base may have restrained selection for yield potential in sunflower. Another study by Demissew [23] on soybean indicated that the average grain yield of the genotypes in the pipeline exceeded that of the first released varieties by 458.67 kg ha^{-1} or 43.91% but it was smaller than the mean yield of the

S No	Variety/Acc. No	Year of release	Breeder/maintainer€	Source	Seed color
1.	DZ-10-4	1974	DZARC/EIAR	Ethiopia	White
2.	Ararti (FLIP 89-84C)	1999	DZARC/EIAR	ICARDA	White
3.	Shasho (ICCV-93512)	1999	DZARC/EIAR	ICRISAT	White
4.	Chefe (ICCV-92318)	2004	DZARC/EIAR	ICRISAT	White
5.	Habru (FLIP 88-42C)	2004	DZARC/EIAR	ICARDA/ICRISAT	White
6.	Ejeri (FLIP-97-263c)	2005	DZARC/EIAR	ICARDA	White
7.	Teji (FLIP-97-266c)	2005	DZARC/EIAR	ICARDA	White
8.	Yelibey (ICCV-14808)	2006	SRARC/ARARI	ICRISAT	Yellowish
9.	ACOS DUIBIE (Monino)	2009	ACOS and DZARC/EIAR	Mexico	White cream

Source: [2,7,28]; €=Abbreviations: DZARC=Debre Zeit Agricultural Research Center; EIAR=Ethiopian Agricultural Research Institute; SRARC=Sirinka Regional Agricultural Research Center; ARARI=Amhara Regional Agricultural Research Institute.

Table 1: Description of Kabuli type chickpea varieties used in the experiment.

Trait€	Location (1)¥	Varieties (8)	Location × Varieties (8)	Error (32)	Mean	CV (%)	R^2
DF	64.46**	228.27**	62.05**	1.85	46.35	2.94	0.98
DM	9600.00**	127.32**	24.00**	4.05	112.70	1.79	0.99
NPBPP	0.13^{ns}	0.40**	0.13**	0.04	2.40	7.92	0.82
NSBPP	261.36**	13.24**	3.01**	0.88	5.38	17.46	0.93
PH	993.82**	19.32^{ns}	11.18^{ns}	7.18	36.07	7.43	0.85
NPoPP$^{\Psi}$	2038.73(0.28**)	1070.27(0.23**)	166.06(0.01^{ns})	72.36(0.01)	33.87(1.48)	25.12(6.40)	0.84(0.88)
NSPPo	0.01^{ns}	0.18**	0.0038^{ns}	0.006	1.16	6.43	0.90
NSPP$^{\Psi}$	3700.17(0.33**)	2851.92(0.32**)	363.36(0.01^{ns})	92.92 (0.01)	40.52(1.54)	23.79(5.73)	0.91(0.92)
GYPP$^{\Psi}$	313.16(0.46**)	23.90(0.03**)	13.61(0.01^{ns})	7.55 (0.01)	10.96(1.02)	25.07(9.34)	0.72(0.74)
GYPha	127647.92^{ns}	1297018.58**	169690.26^{ns}	161195.78	2018.25	19.89	0.70
HSW	24.81**	1080.43**	2.92^{ns}	1.83	33.51	4.03	0.99
BYPha$^{\Psi}$	1164420.64(0.01^{ns})	3674654.17(0.05**)	336003.28(0.01^{ns})	393922.96(0.01)	3510.56(3.53)	17.88(2.24)	0.73(0.72)
GFP	11237.80**	25.14**	40.00**	8.00	66.35	4.26	0.98
HI	0.008**	0.004**	0.005**	0.001	0.57	5.18	0.75
BPR$^{\Psi}$	1435.72(0.24**)	273.60(0.05**)	52.12(0.01^{ns})	35.54(0.01)	31.73(1.48)	18.79(5.41)	0.79(0.78)
SGR$^{\Psi}$	3227.43(0.54**)	392.19(0.07**)	103.39(0.02^{ns})	50.67(0.01)	32.32(1.48)	22.03(6.38)	0.82(0.82)
GYPD$^{\Psi}$	373.51(0.16**)	99.62(0.06**)	22.92(0.01^{ns})	14.67(0.01)	18.20(1.24)	21.04(7.49)	0.75(0.74)

Table 2: Mean squares from combined analysis of variance for seed yield and other traits in Kabuli type chickpea varieties evaluated over two test locations (Debre Zeit and Akaki).

newest released variety. In contrast, [18] on wheat, [19] on tef, [20] on haricot bean and [22] on barley reported respective increases in grain yield potentials of varieties over the period studied.

Generally, the varieties developed through introduction yielded an average grain yield of 2079.61 kg ha^{-1} and exceeded the variety which was developed through local collection by 552.21 kg ha^{-1} (36.15%) (Table 6). This clearly indicated that varieties developed from introduced material contributed the genetic improvement obtained in grain yield of Kabuli type chickpea over the last 35 years. In line with this study, Kebere [20] also indicated that introduced materials contributed a lot for the improvement of the genetic yield potential of haricot bean varieties in Ethiopia (Table 6). On the contrary, Tamene [21] showed that the local collections and hybridization materials were the most important sources of genetic variability contributing to the genetic gain of faba bean over the last 30 years period.

The annual rate of increase in yield potential was estimated from linear regression of mean grain yields of varieties on year of release was 8.42 kg ha^{-1}yr^{-1} (Figure 1A). This clearly indicates that chickpea breeders have made efforts over the last 35 years to improve the yield of Kabuli type chickpea in Ethiopia, but this increase was not significantly different from zero (Table 7), rather they get substantial improvement in hundred seed weight. Likewise, Ersullo [24] noticed that an average rate of increase in grain yield potential per year of release since pre-1984 was non- significant (4.329 kg ha^{-1}yr^{-1}) when tested under the four locations for linseed. Similarly, Koemel [30] indicated the more recent entries failed to improve grain yield of hard winter wheat over that of the long-term check cultivars.

Varieties	Locations		Mean
	Debre Zeit	Akaki	
DZ-10-4	1773.90bc	1280.80e	1527.4cd
Arerti	2920.00a	2659.20a	2789.6a
Shasho	1854.20bc	2161.70abc	2007.9bc
Chefe	2661.90ab	2278.20ab	2470.1ab
Habru	2663.10ab	2271.80ab	2467.4ab
Ejeri	2018.90abc	1792.80bcde	1905.8cd
Teji	1670.30c	1619.40ed	1644.9cd
Yelibey	1811.30bc	1988.30bcd	1899.8cd
Monino	1228.30c	1674.40cde	1451.4d
Mean	2066.87	1969.63	2018.25
CV (%)	24.03	13.98	19.89
R^2	0.67	0.78	0.70

Means followed by the same letter with in a column are not significantly different from each other at P ≤ 0.05 according to Duncan's Multiple Range Test.

Table 3: Mean grain yield (kg ha^{-1}) of Kabuli type chickpea varieties at Debre Zeit and Akaki and averaged across locations.

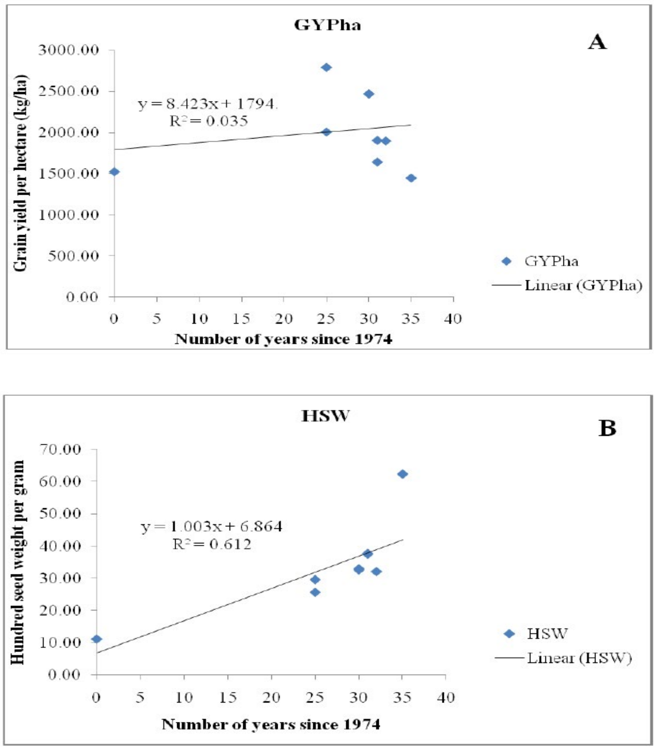

Figure 1: Plot of grain yield (A) and hundred seed weight (B) of Kabuli type chickpea varieties against years of release of the varieties since 1974.

According to Yifru [19] in tef, the genetic gain of some traits was non-significant from 1960 to 1995. Tamene [21] also reported that the genetic gain obtained in faba bean breeding since 1970s was very minimal, that is only 82 kg ha^{-1} in 30 years period or close to 3 kg ha^{-1} yr^{-1}. Similarly, Wondimu [22] in grain yield of malt barley reported that slope of regression since 1973 was not significantly different from zero at each location as well as across locations. In addition, Mackey [31] observed no increase in grain yield of oat varieties for the past 50 years in Sweden.

Hundred seed weight

Like grain yield, the combined analysis of variance revealed that there was no location × variety interaction for hundred seed weight of Kabuli type chickpea, but highly significant (p ≤ 0.01) differences were observed for locations and varieties (Table 8). Mean hundred seed weight ranged from 11.20 g (DZ-10-4) to 62.30 g (Monino) with across location average of 33.52 g (Table 9). The most recently released variety, Monino, showed significantly higher hundred seed weight (seed size) than all the varieties represented in the current study. It exceeded the first older variety (DZ-10-4) by 51.10 g (456.25%) in hundred seed weight. The average hundred seed weight of varieties released in 1974, 1999, 2004, 2005, 2006 and 2009 were 11.20, 27.65, 32.80, 37.60, 32.10 and 62.30 g, respectively. This showed that an increase of 16.45 (146.88%), 21.60 (192.86%), 26.40 (235.71%), 20.90 (186.62%) and 51.10 g (456.25%) in hundred seed weight respectively, over the older variety (Table 4). Therefore, hundred seed weight increase was almost consistent and parallel over the year of release of improved Kabuli type chickpea varieties.

Linear regression hundred seed weight against the years of release indicated annual rate of genetic gain of 1.00 g yr^{-1} (Figure 1B) with a relative annual genetic gain of 8.96% (Table 8), reflecting a significant increase in the trait over the last 35 years of Kabuli type chickpea improvement in Ethiopia (Table 7). Generally speaking, better genetic improvement was obtained from breeding for hundred seed weight than it was from breeding for grain yield as far as Kabuli type chickpea is concerned. Likewise, Amsal [18] in durum wheat, Ortiz [32] in two-row Nordic spring barley, Tamene [21] in faba bean and Ersullo [24] in linseed found that thousand seed weight of modern varieties were heavier than the older ones. Contrary to the present study, [19] in tef, [20] in haricot bean, [22] in food barely noticed non-significant change in seed weight. Highly significant decrease in thousand seed weight with a relative annual reduction of 0.96% was reported in soybean by Demissew [23].

Similar to the grain yield, introduction derived varieties gave an advantage of 25.11 g (224.20%) for HSW over the local collection derived (Table 6) which is contrary to finding of Tamene [21] in faba bean. This indicates that varieties developed from introduced germplasm are the most important sources of genetic material contributing to the genetic improvement in hundred seed weight of Kabuli type chickpea varieties over the last 35 years and the possibility of further improvement in hundred seed weight using this breeding method.

Biomass yield, harvest index and plant height of kabuli type chickpea

Combined analysis of variance for biomass yield indicated non-significant location and location × variety interaction effects. On the other hand, highly significant (p ≤ 0.01) differences were observed among varieties tested for the trait (Table 2). The mean biomass yield of all varieties across the two locations was 3510.56 kg ha^{-1}. The highest mean biomass yield (4948.8 kg ha^{-1}) across locations (Table 9) was recorded from the variety with the highest grain yield, Arerti (Table 3). This variety showed significantly higher biomass yield than all varieties except Chefe and Habru (Table 9). Like that of grain yield, biomass yield also showed inconsistent trend over years of release. Mean biomass yield of varieties developed through introduction was 969.60 kg ha^{-1} (36.61%) higher than mean biomass yield of variety developed through direct selection from landraces (Table 6). Hence, much of the increase in biomass yield was obtained from introduced materials. Similarly, Kebere [20] reported similar finding in haricot bean in Ethiopia. Yifru and Hailu found that varieties developed through intraspecific hybridization gave higher biomass than the varieties developed through landrace selection in tef breeding program.

Variety	Year of release	Mean grain yield (kg ha^{-1})	Increment over DZ-10-4		Mean HSW (g)	Increment over DZ-10-4	
			kg	%		g/HSW	%
DZ-10-4	1974	1527.40	---	---	11.20	---	---
Arerti	1999	2398.75	871.35	57.05	27.65	16.45	146.88
Shasho	1999						
Chefe	2004	2468.75	941.35	61.63	32.80	21.60	192.86
Habru	2004						
Ejeri	2005	1775.35	247.95	16.23	37.60	26.40	235.71
Teji	2005						
Yelibey	2006	1899.80	372.40	24.38	32.10	20.90	186.61
Monino	2009	1451.40	-76.00	-5.00	62.30	51.10	456.25

Table 4: Trends in genetic progress in grain yield and hundred seed weight (HSW) for Kabuli type chickpea varieties released in 1999, 2004, 2005, 2006 and 2009 over the older variety (DZ-10-4) released in 1974.

Varieties	Year of release	Mean grain yield (kg ha^{-1})	Increment over the older variety (DZ-10-4)		Mean HSW (g)	Increment over the older variety (DZ-10-4)		Mean biomass yield (kg ha^{-1})	Increment over the older variety (DZ-10-4)	
			kg ha^{-1}	%		g/HSW	%		kg ha^{-1}	%
DZ-10-4	1974	1527.40	-	-	11.2	-	-	2648.70	-	-
Arerti	1990s	2398.75	871.35	57.05	27.65	16.45	146.88	4252.25	1603.55	60.54
Shasho										
Chefe	2000s	1973.23	445.83	29.19	39.20	28.00	250.00	3406.98	758.28	28.63
Habru										
Ejeri										
Teji										
Yelibey										
Monino										

Table 5: Trends in genetic progress in grain yield, hundred seed weight (HSW) and biomass yield for Kabuli type chickpea varieties released in 1990s and 2000s over the older variety (DZ-10-4) released in 1974.

Variety	Grain yield (kg ha^{-1})	Grain yield increment over local collection		Biomass yield (kg ha^{-1})	Biomass yield increment over local collection		Mean HSW (g)	HSW increment over local collection	
		kg ha^{-1}	%		kg ha^{-1}	%		g/HSW	%
Local collection derived	1527.40	-	-	2648.70	-	-	11.20	-	-
Introduction derived	2079.61	552.21	36.15	3618.30	969.60	36.61	36.31	25.11	224.20

Table 6: Average increments in grain, biomass yield and hundred seed weight (HSW) for Kabuli type chickpea varieties derived from introduction over variety derived from local collection.

Traits	Mean	R^2	b	Intercept
Date of flowering	46.35	0.03	-0.10	49.04
Date of maturity	112.70	0.01	-0.04	113.89
Number of primary branches per plant	2.40	0.09	0.01	2.18
Number of secondary branches per plant	5.38	0.26	-0.07	7.32
Plant height	36.07	0.02	-0.02	36.70
Number of pods per plant	33.87	0.65	-1.03^{**}	61.14
Number of seeds per pod	1.16	0.84	-0.02^{**}	1.57
Number of seeds per plant	40.52	0.90	-1.98^{**}	93.14
Grain yield per plant	10.96	0.00	0.00	10.96
Grain yield per hectare	2018.25	0.04	8.42	1794.57
Hundred seed weight	33.51	0.61	1.00^{*}	6.86
Biomass yield per hectare	3510.56	0.04	14.88	3115.40
Grain filling period	66.35	0.08	0.06	64.85
Harvest index	0.57	-0.0002	0.00	0.58
Biomass production rate	31.73	0.05	0.15	27.81
Seed growth rate	32.32	0.01	0.08	30.06
Grain yield per day	18.20	0.04	0.08	16.14

*, **=Significant at $P \le 0.05$ and $P \le 0.01$, respectively.

Table 7: Estimates of mean values, coefficient of determination (R^2), regression coefficient (b) and intercept for various traits from linear regression of the mean value of each trait for each Kabuli type chickpea variety against the year of variety release since 1974.

Traits	Mean of the older variety	RGG (% per year)	Correlation coefficients (R)			
			R_{GYPha}	R_{YOR}	R_{HSW}	R_{BYPha}
Date of flowering	44.7	-0.23	0.45	-0.17	-0.36	0.49
Date of maturity	110.5	-0.04	0.41	-0.10	-0.35	0.45
Number of primary branches per plant	2.0	0.40	0.81**	0.31	-0.09	0.85**
Number of secondary branches per plant	6.5	-1.13	0.49	-0.51	-0.89**	0.44
Plant height	36.3	-0.07	0.60	-0.14	-0.35	0.56
Number of pods per plant	55.8	-1.84	0.15	-0.80**	-0.91**	0.12
Number of seeds per pod	1.61	-0.95	0.31	-0.91**	-0.71*	-0.36
Number of seeds per plant	90.1	-2.20	-0.07	-0.95**	-0.89**	-0.11
Grain yield per plant	9.8	0.00	0.40	0.00	-0.46	0.34
Grain yield per hectare	1527.4	0.55	---	0.19	-0.28	0.99**
Hundred seed weight	11.2	8.96	-0.28	0.78*	---	-0.21
Biomass yield per hectare	2648.7	0.56	0.99**	0.2	-0.21	---
Grain filling period	65.8	0.09	-0.42	0.29	0.30	-0.48
Harvest index	0.573	-0.03	0.35	-0.06	-0.52	0.19
Biomass production rate	24.5	0.60	0.97**	0.23	-0.17	0.98**
Seed growth rate	25.4	0.33	0.99**	0.11	-0.33	0.99**
Grain yield per day	14.2	0.55	0.98**	0.2	-0.26	0.96**

*, **=Significant at $P \le 0.05$ and $P \le 0.01$, respectively.

Table 8: Estimates of the mean annual relative genetic gain (RGG); and correlation coefficient of all traits with grain yield (R_{GYPha}), year of release of the variety (R_{YOR}), hundred seed weight (R_{HSW}) and biomass yield (R_{BYPha}).

Varieties	Locations				Mean	
	Debre Zeit		Akaki			
	HSW	BYPha	HSW	BYPha	HSW	BYPha$^{\Psi}$
DZ-10-4	12.2^{f}	2967.4^{c}	10.2^{f}	2330.1^{d}	11.2^{f}	2648.7^{e}
Arerti	26.7^{e}	5225.0^{a}	24.6^{e}	4672.5^{a}	25.7^{e}	4948.8^{a}
Shasho	30.9^{d}	3299.9^{c}	28.2^{d}	3811.5^{b}	29.6^{d}	3555.7^{bc}
Chefe	32.7^{cd}	4513.8^{ab}	32.5^{c}	3795.3^{b}	32.6^{c}	4154.5^{ab}
Habru	34.4^{c}	4510.8^{ab}	31.6^{c}	3832.4^{b}	33.0^{c}	4171.6^{ab}
Ejeri	38.1^{b}	3804.7^{ab}c	36.9^{b}	3087.6^{bcd}	37.5^{b}	3446.2^{bcd}
Teji	37.3^{b}	2923.1^{c}	38.1^{b}	2731.4^{cd}	37.7^{b}	2827.2^{de}
Yelibey	33.5^{c}	2986.8^{c}	30.8^{cd}	3226.8^{bc}	32.1^{c}	3106.8^{cde}
Monino	62.0^{a}	2685.3^{c}	62.6^{a}	2785.8cd	62.3^{a}	2735.6^{e}
Mean	34.19	3657.41	32.83	3363.72	33.51	3510.56
CV (%)	3.41	21.33	4.61	12.59	4.03	2.24
R^2	0.99	0.68	0.99	0.82	0.99	0.73

Means followed by the same letter with in a column are not significantly different from each other at $P \le 0.05$ according to Duncan's Multiple Range Test; $^{\Psi}$=Mean separation and CV based on transformed data.

Table 9: Mean hundred seed weight (HSW) and biomass yield (BYPha) of Kabuli type chickpea varieties evaluated at Debre Zeit and Akaki and combined across the two locations.

Linear regression coefficient revealed that biomass yield did not change significantly during the past three decades of Kabuli type chickpea breeding programs (14.88 kg $ha^{-1}yr^{-1}$) (Table 7) with a small relative genetic gain of 0.56% yr^{-1}. The present result was in agreement with the findings of Amsal [18] on bread and durum wheat, Hailu [15] on soybean and Wondimu [22] on food barley who observed that non-significant improvement in biomass yield. Ortiz [32] also found non-significant trend observed in biomass yield of spring barely. Ersullo [24] reported non-significant biomass yield in linseed varieties released since 1984. Conversely, Yifru, Kebere and Tamene [19-21] and Demissew [23] reported that biomass yield was linearly related to variety age and positively and significantly associated to grain yield.

As per combined analysis of variance, harvest index showed highly significant ($p \le 0.01$) differences between locations and among varieties. There was also highly significant location × variety interaction for this trait (Table 2). The mean harvest index of Kabuli type chickpea varieties represented in this study was 0.56 at Debre Zeit and 0.59 at Akaki and 0.57 averages over the two locations (Table 9). This is in agreement with the harvest index reported for haricot bean Kebere [20]. Similarly, higher harvest index value of 0.59 for chickpea was reported by Saxena [33].

Linear regression coefficient for harvest index showed a non-significant annual decrease trend (-0.0002) (Table 7), which was almost zero during the 35 years of Kabuli type chickpea improvement with a relative annual genetic reduction of -0.03% (Table 8). Likewise, Yifru [19] and Kebere [20] found that no change in harvest index of tef and haricot bean respectively. Demissew [23] also noticed that non-significant annual reduction in harvest index of soybean. In contrast to this, Hailu [15] and Jin [16] revealed that harvest index increased significantly with year of release of soybean varieties. The varieties in the present study showed a small decrease in harvest index may be the higher non-significant increment of biomass yield than grain yield.

There was a non-significant difference among varieties while the effect of location was highly significant for plant height (Table 2).

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However, the annual genetic gain of plant height over the past 35 years of breeding was -0.02 cm and was not significantly different from zero (Table 7) with relative genetic gain of -0.07% yr^{-1} (Table 8). Similarly, a non-significant reduction in plant height was reported by Kebere [20] on haricot bean.

Yield components of kabuli type chickpea

Except number of primary branches $plant^{-1}$ and number of seeds pod^{-1}, mean squares of locations from combined analysis of variance were highly significant ($p \leq 0.01$) for number of secondary branches $plant^{-1}$, number of pods $plant^{-1}$, number of seeds $plant^{-1}$ and grain yield $plant^{-1}$. Combined analysis of variance across the two locations indicated non-significant location × variety interaction for all yield components except number of primary branches $plant^{-1}$ and number of secondary branches $plant^{-1}$ which showed highly significant interaction effects. Furthermore, all the above mentioned yield components showed highly significant difference among varieties (Table 2).

Mean number of primary branches $plant^{-1}$ and secondary branches $plant^{-1}$ from combined analysis was found to be 2.40 and 5.38 respectively (Table 10). In both locations (Debre Zeit and Akaki) the highest yielding variety Arerti, had the highest number of primary branches $plant^{-1}$ and secondary branches $plant^{-1}$. Estimated annual gains of both number of primary branches $plant^{-1}$ and secondary branches $plant^{-1}$ of Kabuli type chickpea varieties over the last 35 years was 0.01 and -0.07 branches $plant^{-1}$ yr^{-1}, which were not significantly different from zero (Table 7); and relative genetic gain of 0.40 and -1.13% yr^{-1} (Table 8), respectively.

The average number of pods $plant^{-1}$, number of seeds pod^{-1} and number of seeds $plant^{-1}$ of Kabuli type chickpea varieties, average over locations were 33.87, 1.16 and 40.52 respectively (Table 10). Most recently released varieties which had heavier seed weight (larger seed size) and low yield have low number of pods $plant^{-1}$, seeds pod^{-1} and seeds $plant^{-1}$. Generally, there was a decreasing trend in number of pods $plant^{-1}$, number of seeds pod^{-1} and number of seeds $plant^{-1}$ over the 35 years period of Kabuli type chickpea improvement as it can be seen from highly significant negative linear regression coefficients (Table 7) and relative genetic gain of -1.84, -0.95 and -2.20% yr^{-1} for the three traits (Table 8), respectively. Similarly, Tamene [21] observed that number of seeds $plant^{-1}$, number of pods $plant^{-1}$, number of podding nods $plant^{-1}$ and number of pods $node^{-1}$ followed a decreasing trend against time in faba bean breeding program, that is, the older the variety the higher the value for the component traits and vice versa. However, [20] in haricot bean reported that number of pods $plant^{-1}$ and number of seeds pod^{-1} showed a non-significant increasing trend for the period studied.

The negative breeding progress in secondary branches $plant^{-1}$, number of pods $plant^{-1}$, number of seeds pod^{-1} and number of seeds $plant^{-1}$ may be considered as the result of a negative compensatory response to the radical increment in hundred seed weight (seed size) during the same period. Therefore, for simultaneous improving seed size, number of pods $plant^{-1}$ and number of seeds $plant^{-1}$ a compromise between selection progresses for both traits must be made, or the breeder must set minimum standards for one trait while selecting for the other.

Phenological and productivity traits

Phenological traits: The combined analysis of variance showed that days to flowering, days tomaturity and grain filling period had highly significant ($P \leq 0.01$) differences between locations and among varieties. The location x variety interaction effect also showed highly significant differences for these traits (Table 2). The average values of phenological traits represented in this study was 47.44, 99.37 and 51.93 days at Debre Zeit and 45.26, 126.04 and 80.78 days at Akaki, respectively. In this study, most of recently released varieties relatively took intermediate to short days to reach flowering and maturity. Early maturity is advantageous in chickpea to avoid terminal moisture stress and make adequate use of available soil moisture during growth period, as chickpea is usually grown on conserved soil moisture, where soil moisture reduces towards maturity [34].

From the slope of regression line, there was a negative trend for days to flowering and days to maturity but not significantly different from zero (Table 7). However, grain filling period showed increasing trend, still it was not significantly different from zero. Likewise, Wondimu [22] reported that all of the three phenological traits showed a non-significant decreasing tend in food barely. Hailu [15] observed insignificant increment with delayed flowering and maturity in soybean varieties. However, Kebere [20] and Tamene [21] found a non-significant increase in days to maturity in haricot bean and faba bean

Varieties	Trait													
	DF	DM	NPBPP	NSBPP	PH	NPoPP$^{\Psi}$	NSPPo	NSPP$^{\Psi}$	GYPP$^{\Psi}$	GFP	HI	BPR$^{\Psi}$	SGR$^{\Psi}$	GYPD$^{\Psi}$
DZ-10-4	44.7^{cd}	110.5^{cd}	2.0^{d}	6.5^{ab}	36.3	55.8^{a}	1.61^{a}	90.1^{a}	9.8^{bc}	65.8^{bc}	0.573^{abc}	24.5^{d}	25.4^{cd}	14.2^{bc}
Arerti	55.5^{b}	118.3^{b}	3.0^{a}	7.2^{a}	35.9	41.7^{ab}	1.07^{bc}	44.7^{bc}	11.3^{ab}	62.8^{c}	0.56^{bc}	43.1^{a}	46.4^{a}	24.3^{a}
Shasho	58.3^{a}	122.5^{a}	2.5^{b}	6.4^{ab}	36.6	49.2^{a}	1.06^{bc}	52.3^{b}	14.6^{a}	64.2^{bc}	0.565^{bc}	29.2^{cd}	32.0^{b}	16.5^{bc}
Chefe	43.8^{cde}	111.5^{c}	2.4^{bc}	4.9^{c}	37.9	29.6^{cd}	1.13^{b}	32.7^{de}	10.7^{ab}	67.7^{ab}	0.60^{ab}	38.2^{ab}	39.2^{ab}	22.7^{a}
Habru	43.7^{def}	110.2^{cd}	2.4^{bc}	5.6^{bc}	38.8	30.5^{cd}	1.15^{b}	35.0^{cde}	11.5^{ab}	66.5^{abc}	0.59^{ab}	38.8^{ab}	40.3^{ab}	22.9^{a}
Ejeri	42.2^{efg}	110.0^{cd}	2.3^{bc}	4.6^{c}	36.4	24.6^{d}	1.12^{b}	27.5^{e}	10.1^{b}	67.8^{ab}	0.55^{cd}	32.4^{bc}	30.7^{bc}	17.8^{b}
Teji	41.5^{g}	111.3^{c}	2.3^{bc}	5.0^{c}	32.7	26.8^{cd}	1.10^{bc}	29.4^{e}	10.2^{b}	69.8^{a}	0.58^{abc}	25.9^{cd}	24.8^{cd}	15.0^{bc}
Yelibey	45.5^{c}	111.7^{c}	2.4^{bc}	6.1^{ab}	35.5	34.9^{bc}	1.16^{b}	40.8^{bcd}	13.0^{ab}	66.2^{abc}	0.61^{a}	28.1^{cd}	29.7^{bc}	17.2^{b}
Monino	42.0^{fg}	108.3^{d}	2.2^{cd}	2.1^{d}	34.5	11.9^{e}	1.02^{c}	12.2^{f}	7.5^{c}	66.3^{abc}	0.52^{d}	25.5^{cd}	22.3^{d}	13.3^{c}
Mean	46.35	112.70	2.40	5.38	36.07	33.87	1.16	40.52	10.96	66.35	0.57	31.73	32.32	18.20
CV (%)	2.94	1.79	7.92	17.46	7.43	6.40	6.43	5.73	9.34	4.26	5.18	5.41	6.38	7.49
R^2	0.98	0.99	0.82	0.93	0.85	0.84	0.90	0.91	0.72	0.98	0.75	0.79	0.82	0.75

Means followed by the same letter with in a column are not significantly different from each other at $P \leq 0.05$ according to Duncan's Multiple Range Test;

$^{\Psi}$=Mean separation and CV based on transformed data.

Table 10: Mean values of phenological traits, yield components and productivity traits of Kabuli type chickpea varieties combined over locations (Debre Zeit and Akaki).

breeding, respectively. In contrast, Demissew [23] noticed that both days to flowering and maturity showed significant increment over years of soybean improvement. This author also indicated that grain filling period showed a non-significant increasing trend in the period studied.

Productivity traits: Combined analysis of variance showed highly significant differences between locations and among varieties tested for all productivity traits (biomass production rate, seed growth rate and grain yield day^{-1}) while the location × variety interaction effect was non-significant for all the traits (Table 2). The mean biomass production rate, seed growth rate and grain yield day^{-1} of Kabuli type chickpea varieties recorded from the combined analysis averaged over locations were 31.73, 32.32 and 18.20 kg ha^{-1}day^{-1} (Table 10), respectively.

Linear regression showed a non-significant increasing trend for biomass production rate, seed growth rate and grain yield day^{-1} for the past 35 years of Kabuli type chickpea breeding program (Table 7) with relative genetic gains of 0.60, 0.33 and 0.55% yr^{-1} (Table 8), respectively. This indicated that breeding did not markedly affect these traits for the last three decades. Similarly, Yifru [19] observed a non-significant increase in both total grain sink filling rate and biomass production rate of tef varieties over the 35 years of variety release. The non-significant increasing trend grain yield day^{-1} observed in the present study was in agreement with the finding of Demissew [23] in soybean improvement. Amsal [18] and Wondimu [22] also found that biomass production rate on year of release of the varieties has showed no indication of improvement in the study period. In the same study, however, a significant increasing trend in biomass production rate, seed growth rate and grain yield day^{-1} was reported as opposed to the present study in haricot bean for the 26 years period Kebere [20].

Yield related traits associated with grain yield potential improvement

The correlation coefficients of grain yield, hundred seed weight and biomass yield with all the traits studied are presented in Table 8. The correlation coefficients indicated that grain yield showed a highly significant ($p \leq 0.01$) association with biomass yield, while it had non-significant and positive association with harvest index. Hence, the results herein demonstrated that increasing the biomass yield would be a more efficient way to boost up Kabuli type chickpea grain yield than would harvest index. Moreover, biomass yield showed significant positive relation with number of primary branches plant^{-1}, biomass production rate, seed growth rate and grain yield day^{-1}, but non-significant association with all other traits. In agreement with the present study, [19] on tef, [20] on haricot bean, [21] on faba bean, [15] and [23] on soybean found that highly significant positive correlations between grain yield and biomass yield, but no significant correlation between grain yield and harvest index. Similarly, Bicer [35] on chickpea reported that biological yield is positively correlated with seed yield, which is an important character for determining seed yield. The reverse is true in the finding of Khan [36] who reported that grain yield positively and highly significantly association with harvest index but non-significantly with biomass yield. As a result, variation in harvest index had a possibility of improving and boosting up grain yield in chickpea. Singh [37] on chickpea found that biological yield and harvest index had significant positive association with seed yield and therefore selection for these traits both together would lead to high seed yield. Conversely, Amsal [18] on bread wheat and Wondimu [22] on food barley reported significant and positive relation between harvest index and grain yield and non-significant association between biomass and grain yield.

The association between grain yield and plant height was also positive and statistically non-significant (Table 8). Different authors also found non-significant correlation between grain yield and plant height [38-40]. Similarly, Yifru, Kebere, Tamene [19-21] and Hailu [15] observed no relation between grain yield and plant height respectively in tef, haricot bean, faba bean, and soybean. However, Wondimu [22] on food barley and Jin [16] on soybean observed negative correlation between plant height and grain yield.

In general, grain yield in the modern varieties appears to be associated more with the production of a higher biomass than with a higher partitioning efficiency to the grain sink. This indicated that biomass yield may serve as an index for identifying chickpea varieties with higher seed yield. Hence, it is of vital importance to give due attention to biomass yield while selecting Kabuli type chickpea varieties for production and commercial cultivation.

Highly significant positive correlation was observed between grain yield and number of primary branches plant^{-1}, while the association of grain yield with number of secondary branches plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1} and grain yield plant^{-1} was positive and non- significant. This indicates that number of primary branches plant^{-1} is still an important trait used for selection criteria in breeding for further improvement in grain yield of both chickpea types. Among yield components number of seeds plant^{-1} and hundred seed weight showed negative and no-significant association with grain yield (Table 8). Similarly, [40] indicated that number of primary branches plant^{-1} showed highly significant positive correlation with grain yield whereas number of secondary branches plant^{-1} showed non-significant association with grain yield on chickpea. Sharma [41] also reported primary branches plant^{-1} showed highly correlation with grain yield. In contrast, Saleem [38] on chickpea found that there was significant and negative relation between grain yield and number of secondary branches plant^{-1}, but the association of primary branches plant^{-1} with grain yield was non-significant. According to Toker, Sharma and Ali [42-44] grain yield was significantly and negatively correlated with hundred seed weight. Similarly, there have been few cases of negative association between seed size and grain yield, apparently as a result of few seeds pod^{-1} and few pods plant^{-1}, characteristics of larger seeded type [45]. Another report which was almost similar to the present study reported by Tamene [21], who reported non-significant association between grain yield and seed weight plant^{-1}, thousand seed weight, number of seeds pod^{-1}, number of seeds plant^{-1} and number of pods plant^{-1}.

One of the economical traits in Kabuli type chickpea, hundred seed weight, showed significantly negative associations with number of secondary branches plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1} and number of seeds plant^{-1} (Table 7). Similarly, Kumar, Naseem and Temesgen [46-48] on Kabuli type chickpea observed that hundred seed weight had significant and negative phenotypic correlation with number of pods plant^{-1}, number of seeds pod^{-1} and number of seeds plant^{-1}. Another study by Sharma [41] showed that number of branches plant^{-1} and number of pods plant^{-1} showed highly negative association with hundred seed weight. Negative association between hundred seed weight and number of seeds per pod indicates a compensatory relationship between them. More seeds per pod could result in the reduction of the average seed size because of competition among seeds for limited food reserves [49].

Positive and non-significant association of grain yields with days to flowering and maturity was observed in the current study (Table 8). The correlation between grain yield and grain filling period was negative but not significant. Hasan [39] also reported positive and non-significant correlation between grain yield and days to flowering as well as days to maturity. Conversely, Arshad [50] showed non-significant negative associations of grain yield with days to flowering and maturity. Similarly, Temesgen [48] reported grain filling period to be positively non-significantly associated with grain yield.

The correlation coefficients for grain yield day^{-1}, seed growth rate and biomass production rate was highly significant ($P \leq 0.01$) and positive with grain yield (Table 8). This clearly showed that improvement in these traits was markedly concurrent to the yield improvement in the past and can further be exploited in future breeding. In a similar study on haricot bean, Kebere and Tamene [20,21] on faba bean found positive and significant correlation of grain yield with each of these traits.

Stepwise regression analysis, using grain yield as dependent variable (Table 11) indicated that, biomass yield and harvest index were the most important traits which greatly contributed most of the variation in grain yield. Hence, 97% of the total variations in grain yield of Kabuli type chickpea varieties were explained by biomass yield alone and 99.9% by biomass yield and harvest index altogether. In previous study on tef and haricot bean, Yifru and Kebere [19,20] reported that biomass yield was the single most important trait that contributed 56.7 and 82.7% of the variation in grain yield among varieties respectively. About 96% of the variation in faba bean grain yield was explained by economic growth rate, whereas economic growth rate, number of pod plant^{-1}, harvest index and biomass together accounted for 99% of the variation in grain yield Tamene [21]. Similarly, Wondimu [22] reported that harvest index, biomass yield and biomass production rate were traits which contributed to gain in grain yield of food barley varieties. Demissew [23] also found that biomass yield, harvest index and number of branches plant^{-1} were traits which contributed most to the variation in grain yield. Accordingly 93.0% of the variation in grain yield was contributed by biomass yield, 99.5% by biomass yield and harvest index, and 99.8% by biomass yield, harvest index and number of branches plant^{-1} together. Therefore, it can be considered that changes in the above trait had probably contributed to the changes in grain yield during the last 35 years of breeding Kabuli type chickpea in Ethiopia.

The stepwise regression analysis also showed that, for hundred seed weight (seed size), which is also another economic trait in Kabuli type chickpea: number of pods plant^{-1} had a decreasing effect, contributed to the variation among the varieties in seed size. About 83% of the variation in hundred seed weight was accounted for by number of pods plant^{-1}. Similarly, Tamene [21] was reported 88.48% of the variability in thousand seed weight was accounted for by number of pods plant^{-1} alone and 92.56% when both number of pods and grain filling period together.

Grain yield				
Independent variables	Intercept	Regression coefficient (b)	R^2	VIF
Biomass yield hectare^{-1}	-1608.12475	0.56669**	0.9717	1.037
Harvest index		2861.87258**	0.9990	1.037
Hundred seed weight				
Number of pods plant^{-1}	64.533	-0.915**	0.8298	1.00

** =Significant difference at $p \leq 0.01$, VIF=Variance Inflation Factor.

Table 11: Summary of selection from stepwise regression analysis of mean grain yield and hundred seed weight of Kabuli type chickpea as dependent variable on the other traits as independent variables.

Conclusions

Yield potential improvement of Kabuli type chickpea breeding was relatively less marked probably owing to stringent seed size requirements. Therefore, better genetic progress was obtained from breeding for hundred seed weight/seed size within a short period of time than it was from breeding for grain yield for the last three decades for this chickpea type. The improvement of hundred seed weight in Kabuli type chickpea was significantly and negatively correlated with number of secondary branches plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1} and number of seeds plant^{-1}. Therefore, the negative association between hundred seed weight and with these traits indicates that a compensatory relationship between them.

Finally, about 80% of the varieties were derived from introduction which is crossing materials at ICRISAT and ICARDA whereas the remaining varieties were developed through local selection/collection. Varieties developed from crossing and introduced germplasm was the most important sources of genetic material contributing to the genetic improvement of grain yield, biomass yield and hundred seed weight/seed size for the last three decades which revealed chickpea breeding effort should focus on crossing works than landrace selection.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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