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ORIGINAL ARTICLE

Genetic improvement in grain yield potential and associated traits of food barley (*Hordeum vulgare* L.) in Ethiopia

Wondimu Fekadu[1*], Habtamu Zelekle[2] and Amsalu Ayana[3]

[1]Holetta Agricultural Research Center, EIAR, P.O. Box 2003,Addis Ababa, Ethiopia.

[2]School of Plant Sciences, Haramaya University, P. O. Box 138, Dire Dawa, Ethiopia.

[3]Oromia Agricultural Research Institute, P.O. Box, 81265, Addis Ababa,

***Corresponding author:** wfekadu@yahoo.com

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ABSTRACT

An experiment was conducted using ten food barley varieties in RCBD with four replications at three testing locations during 2009 main cropping season. The objectives of the study were to estimate the progress made in improving grain yield potential of barley varieties and changes in agro-morphological traits associated with yield potential improvement. Analyses of variances showed significant differences among varieties for all traits except grain filling period, biomass yield and biomass production rate. Grain yield has increased from 3314.8 kg ha^{-1} to 5088.6 kg ha^{-1} during the period from 1970 to 2006 in Ethiopia. An increment in grain yield of modern varieties over the farmers' variety Balami and oldest improved variety IAR/H/485 was 1690 kg ha^{-1} (51%) and 1388 kg ha^{-1} (38%) respectively. Based on regression of mean grain yield versus the number of year's elapsed since1970/1973, yield gain has risen at an average rate of 44.24 kg ha^{-1} (1.34%) and 42.96 kg ha^{-1} (1.19%) per year of release, respectively. In this study absence of yield plateau indicated the potential for further progress in grain yield in food barley. Besides, significantly increasing trends parallel to variety release were also evident for harvest index, reduced plant height, total grain sink filling rate, spike grain sink filling rate and spike per plant whereas biomass yield remain unmodified. Correlation analysis indicated that , grain yield was significantly and positively correlated with harvest index, total grain sink filling rate, spike grain sink filling rate and kernel weight per spike. Moreover, grain yield, harvest index, total grain sink filling rate, spike grain sink filling rate, plant height and spike per plant were significantly associated with year of release of varieties. On the other hand, stepwise regression analysis depicted that harvest index and biomass yield accounted for 73% of the variation among the varieties in grain yield.

Keywords: Agronomic trait, food barley, genetic gain, yield potential, yield plateau

INTRODUCTION

Barley (*Hordeum vulgare* L.) is an annual cereal crop, which belongs to the tribe Triticeae of family Poaceae (Harlan, 1976; Martin *et al.*, 2006). It is a diploid (2n=14) plant with high degree of self-fertilization. Barley is the most widely grown crop over broad environmental conditions. It has persisted as a major cereal crop through many centuries and it is the world's fourth important cereal crop after wheat maize and rice (Martin *et al.*, 2006). Barley has a long history of cultivation in Ethiopia and it is reported to have coincided with the beginning of plow culture (Zemede, 2000). It is the most important crop with total area coverage of 1,129,112 hectares and total annual production of about 1.7 million tons in main season (CSA, 2010). Barley is also a principal *Belg* season crop second to maize in area coverage and production (Birhanu *et al.*, 2005; CSA, 2008). In the highland of the country barley can be grown in Oromia, Amhara, Tigray Regional States and part of SNNP in the altitude range of 1500 and 3500 m, but it is predominantly cultivated between 2000 and 3000 masl (Berhane *et al.*, 1996). Under extreme marginal conditions of drought, frost and poor soil fertility, barely is the most dependable cereal and is cultivated on highly degraded mountain slopes better than other cereal crops in the highland of Ethiopia (Ceccarelli *et al.*, 1999). As barley is early harvested crop, it is popular hunger breaker or relief crop during season of food shortage in some parts of the country (Baye and Berhane, 2006).

In Ethiopia, barley types are predominantly categorized as food and malting barley based on their uses while the highest proportion of barley production area is allocated for food barley type. Food barley is principally cultivated in the highland where the highest consumption in the form of various traditional foods and local beverages from different barley types (Zemede, 2000). Ceccarelli *et al.* (1999) also indicated that barley grain accounts for over 60% of food for the highland people in Ethiopia, for which it is the main source of calories. According to Birhanu *et al*. (2005) barley kernel is used in diversity of recipes and deep rooted in the culture of people's diets.

Besides its grain value, barley straw is an indispensable component of animal feed especially during the dry season in the highland where feed shortage is prevalent (Girma *et al*., 1996). Barley straw is also used in the construction of traditional huts and grain stores as thatching or as a mud plaster, as well as for use as bedding in the rural area (Zemede, 2000).

In Ethiopia, research on barley improvement was started in the 1950s through introduction of exotic germplasm and collections from local landraces with an objective to improve grain yielding potential, and stability with good gain quality (Hailu *et al.*, 1996). As a result of existence of genetic variability for various economic traits in the country and favorable access to international germplasm exchange, barley breeders have so far developed many barley varieties (Birhanu *et al*. 2005). Among the released and registered food barley varieties IAR/H/485, A hor 880/61, HB-42, Ardu-12-60B, Shege, Abay, Misrach, Dimtu and BH-1307 are the dominant ones.

A successful breeding program is expected to generate genetic gain in grain yield, yield component and resistance to biotic and a biotic stresses. Genetic improvement can be studied either by estimating level of genetic advance from a single or a series of selection cycles made at a time or from a long-term breeding effort made by a breeding program (Waddington *et al.*, 1986). Likewise, estimation of genetic progress from a breeding program and periodic evaluation of advancement in the genetic gain of a crop is required to understand changes produced by breeding activities, to assess the efficiency of past improvement works in genetic yield potential and suggest on future selection direction to facilitate further improvement. Despite allocation of considerable resources to barley variety development, there were no studies to determine the progress in genetic gain in grain yield potential and associated agronomic traits. Hence, the present study was executed to estimate the progress made in improving genetic yield potential of barley and to assess changes in morpho- agronomic characteristics and thereby to identify their association with genetic gain in food barley varieties.

MATERIALS AND METHODS

Description of the Study Sites

The experiment was executed at Adadi and Jeldu testing sites and Holetta Agricultural Research Center during the main cropping season of 2009 under rain-fed condition. Holetta Agricultural Research Center is located at 9^0 00'N, 38^0 30'E and an altitude of 2400 m above sea level. It is 29 km away from Addis Ababa on the road to Ambo and characterized with mean annual rainfall of 1044 mm, mean relative humidity of 60.6%, and mean maximum and minimum temperature of 22.1^0C and 6.2^0C, respectively. The main rainy season is from June to September, which accounts for 70% of the rainfall while the remaining thirty percent is from February to April. The soil of the center is Nitosol, which is characterized with average organic matter content of 1.8%, Nitrogen 0.17%, pH 5.24, and phosphorus 4.55 ppm. Adadi testing site is 67 km away from Addis Ababa on the road to Butajira. It is situated at 8^0 38′N and 38^0 30′E with an altitude of 2050 m above sea level with an average annual rain fall of 900 mm. Soil of Adadi area is characterized as Eutric Luvisol with organic carbon (1.16 %), Nitrogen (0.15%), phosphorus (8.70 ppm), and pH (6.32). Jeldu sub- station is one of the cool season crops trial sites, 38 km from Ginchi town. It is located at an altitude of 2800m above sea level in the vicinity of Gojo town at 9^0 16′N and 38^0 05′E. It receives average annual rain fall of 1200 mm with an average annual maximum and minimum temperature of 16.9^{0}C and 2.06^{0}C, respectively. Soil type of Jeldu area is characterized as Humic Nitosol (Gemechu, 2007).

Experimental Materials

The study was executed using different food barley varieties (Table 1). It was comprised of nine barley varieties released since 1975 and one farmers' variety.

Table 1. Description of test barley varieties

Variety name/ Acc. No	Origin/Description	Year of release	Row type
Balami	Dominant farmers' variety in Shewa	-	Irregular
IAR/H/485	Landrace selection from shewa collection	1975	Six row
Ahor880/61(CI-331848)	Introduction	1980	Six row
HB-42	A cross made at HolettaIAR/H/81/ Comp29// Comp 14/20/Cost	1985	Six row
Ardu-12-60B	Landrace selection from Arsi	1986	Six row
Shege (Line 3336-20)	Landrace selection from Arsi	1996	Six row
Abay (Line 3357-10)	Landrace selection from Arsi	1998	Six row
Misrach (Kulumsa 1/88)	landrace selection from Arsi	1998	Six row
Dimtu(Line 3369-19)	landrace selection from Arsi	2001	Irregular
HB-1307	A cross made at Holetta from Awura gebs-1/IBON 93/91	2006	Six row

Experimental Design and Treatments

The experiment was conducted in a randomized complete block design with four replications. Each treatment was planted to a plot area of 3.0 m^2 consisting of six rows of 2.5 m long spaced 0.2 m apart between rows, 0.4 m between plots and 1.5m between blocks. Seed was treated with Gaucho® (Imidachlopride 70% WS) chemical at 185 g with 125 kg seed per hectare to prevent barley shoot fly damage. Moreover, seeds were sown at a rate of 85 kg ha^{-1}. Fertilizer was applied during planting in the form of urea and diamonium phosphate (DAP) at the rate of 41/46 N/P_2O_5 ha^{-1}. The experiment was planted from June 20 to July 12, 2009.

The first weeding was carried out at thirty days after crop emergence and the second weeding was performed thirty days after the first weeding.

Propiconazol (Tilt 250 EC) fungicide was sprayed at the rate of 0.5 l/ha in 200 liter of water to control foliar disease starting from 60 days after planting by monitoring the field. The trial field was regularly prevented from bird damage by daily laborers. Besides, nylon and sisal string were used as a modified net to prevent lodging. Generally, strict close supervision and maximum care was taken in this experiment to minimize the possible occurrence of yield limiting factors which could affect yield potential expression of the varieties as stated by Waddington *et al.*(1986); Evans and Fischer (1999); Abeledo *et al.*(2003).

Data Collection

Data on agro-morphological traits of barely varieties were collected on plot and plant basis according to standard procedure of Anderson *et al*. (2002) and descriptors for barley (IPGRI, 1994).

Data Analysis

All measured agro-morphological traits were subjected to analyses of variance using SAS software version 9.00 (Anonymous, 2002). Bartlett's test for homogeneity of variance was carried out to determine the validity of the individual experiment and thereafter, combined analyses of variance were performed using PROC GLM procedure. Log transformation was used according to Gomez and Gomez (1984) for those traits which exhibited heterogeneity of variances in barley trial for traits: days to maturity, grain filling periods, and spike grain sink filling rate and spike length. Mean separation was carried out using Duncan's Multiple Range Test (DMRT) at 5% of significance.

Linear regression analysis was used to calculate the genetic gain for each trait considered in the study. The breeding effect was estimated as a genetic gain for grain yield and other agronomic traits in barley improvement by regressing mean of each character for each variety against the year of release of that variety using PROC REG procedure. The relative gain achieved over the year of release period for traits under consideration was determined as a ratio of genetic gain to the corresponding mean value of oldest variety and expressed as percentage. Pearson product moment correlation coefficients among all characters were computed using means of each variety in each year using PROC CORR procedure. Stepwise regression analysis was done using PROC REG procedure to identify best contributing traits to grain yield as a dependent variable (Mason *et al*., 2003).

Individual location ANOVA Model

$$\mathbf{Y_{ij} = \mu + G_i + B_j + e_{ij}}$$

Y_{ij} = observed value of genotype i in block j, μ = grand mean of the experiment, G_i = effect of genotype i, B_j = effect of block j, e_{ij} = random error effect of genotype i in block j

Combined ANOVA Model

$$\mathbf{Y_{ijk} = \mu + G_i + E_j + GE_{ij} + B_{k(j)} + e_{ijk}}$$

Y_{ijk} = observed value of genotype i in block k of location j

μ = grand mean, G_i = effect of genotype i, E_j = Environmental or location effect

GE_{ij} = the interaction effect of genotype i with location (environment) j

$B_{k(j)}$ = effect of block k in location (environment) j

e_{ijk} = random error (residual) effect of genotype i in block k of location(environment) j

The functional form of linear relationship between a dependent variable **Y** and independent variable **X** is represented by the following equation. $\mathbf{Y = \beta_0 + \beta_1 x}$, Where Y= the value of the dependant variable, X= the independent variable, β_0 = the intercept of the line, β_1= the regression coefficient or slope of line, or the changes in Y per unit change in X.

$$\text{Annual rate of gain (b)} = \frac{CovXY}{VarX}$$

Where: Cov = Covariance, Var = Variance, X= the year of release of the variety, Y= the mean value of each character for each variety. The relative annual gain achieved over the last 36 years for food barley was determined as a ratio of genetic gain to the corresponding mean value of oldest variety and expressed as percentage.

$$r_{xy} = \frac{Cov(X,Y)}{\sqrt{V(X)V(Y)}}$$

Where: r_{xy} = correlation coefficient between x and y, Cov (x,y) = Covariance between x and y; V(x) = Variance of x, V(y) = Variance of y

RESULTS AND DISCUSSION

Yield Potential Performance of the Varieties The combined analyses of variance across the three test locations showed significant differences among the test varieties, locations and variety by location interaction for most of the traits (Table 2). Significant differences were observed among tested varieties for all traits except, biomass yield, grain filling period, and biomass production rate. Mean squares of locations were significantly ($P< 0.01$) different for all agro-morphological parameters. However, spike length and kernel number per spike were found to be no significant, whereas mean squares of locations for grain yield was significantly different at ($P< 0.05$). Varieties were also markedly ($P< 0.01$) different from each other except grain filling duration, biomass yield and biomass production rate while significant difference among varieties was detected at ($P< 0.05$) for spike grain sink filling rate.

Mean squares for variety by location interaction effects were significant for most of the traits except grain yield, tiller per plant and kernel protein content; indicating differential response of the varieties to test locations for those traits. Grain yield which is an important agronomic parameter was not significantly affected by interaction effect that, varieties were performed nearly similarly in the test locations. This might be due to the past breeding endeavors to develop varieties that perform relatively well over the range of environments for grain yield potential in barley. The relative proportion of the total variation contributed by the interaction effect was different for different traits depicting variability of the **traits** differential responses of the traits to environmental factors. Mean performance of ten food barley varieties (listed in chronological order of release) for grain yield, biomass yield and harvest index are presented in Tables 3. The mean grain yield of all food barley varieties represented in the yield potential trial was 4673.3 kg ha^{-1} at Holetta, 3954.2 kg ha^{-1} at Jeldu and 4061.6 kg ha^{-1} at Adadi. Grain yield potential of Adadi was at par with that of Jeldu while that of Holetta showed significantly higher than both locations. The relative low yield of Jeldu may be partly attributed to extended heavy rain which highly saturated the soil during vegetative growth stage accompanied with desiccating dry wind at later stage. The recently released stiff straw variety HB-1307 gave the highest grain yield though it was at par with preceding varieties Ardu-12-60B, Misrach, and Dimtu. Grain yield of IAR/H/485, Ahor 880/61, and HB-42 varieties were not markedly different from farmers' variety Balami. Location mean grain yield of food barley varieties ranged from 2812.2 kg ha^{-1} produced by Ahor 80/61 at Adadi to 5256.6 kg ha^{-1} produced by HB-1307 at Holetta. The lowest and highest mean grain yields were recorded at Holetta for Balami (3637.0 kg ha^{-1}) and for HB-1307 (5256.6 kg ha^{-1}), respectively. However except Balami, IAR/H/ 485 and HB-42, all varieties showed similar yield performance with HB-1307. On the other hand, at Adadi mean grain yield ranged from 2812.2 kg ha^{-1} for A hor 880/61 to 5017.6 kg ha^{-1} for HB-1307 variety. Abay, Miserach and Dimtu showed similar performance with HB-1307, but were significantly higher than the obsolete varieties Ahor 880/61 and Balami. Moreover, the lowest and highest grain yield at Jeldu was 3062.4 kg ha^{-1} and 4991.5 kg ha^{-1} for IAR/485 and the recent HB-1307 variety respectively. Except Balami, IAR/H/ 485 and Ahor 880/61 all varieties showed similar yield performance with the latest varieties at this location. In this study, it was shown that Dimtu and HB-1307 barley varieties had significantly higher grain yield than the obsolete varieties (Balami and IAR/H/485) at all the test locations reflecting substantial grain yield potential improvement in food barley in the country.

Table 2. Mean squares of agronomic traits from combined analysis of variance for food barley varieties over the three test locations

		Mean squares (MS)					
No.	Trait	Location (2)$^{\psi}$	Genotype(9)	Loc x Gen (18)	Error (81)	Mean	CV (%)
1	DF	2848.61**	516.65**	33.78**	0.89	94.71	0.99
2	DM	17104.03**	1141.27**	100.15**	6.03	150.59	0.32
3	GFP	11431.36**	164.54^{ns}	159.77**	6.22	55.88	1.06
4	TKW	352.38**	169.73**	13.37**	2.47	46.17	3.40
5	HLW	71.47**	55.65**	6.19**	2.66	64.94	2.51
6	BMY	271918124.7**	14630134.1^{ns}	10045830.9**	3498641.00	11912.70	15.70
7	GY	6019651.87*	386281.91**	747914.60^{ns}	509505.40	4229.68	16.88
8	HI	1014.72**	384.06**	72.25**	19.57	36.94	3.29
9	BMPR	11668.4**	734.22 ^{ns}	471.03**	153.94	80.51	15.51
10	GSFR	24954.28**	1522.29**	453.45**	189.86	81.34	16.94
11	SGSFR	8058.47**	355.11*	110.86**	22.24	52.43	2.46
12	PH	676.31**	790.73**	54.45**	19.45	113.31	3.89
13	TPP	24.77**	3.69**	1.02ns	0.62	6.67	11.82
14	SPP	13.14**	5.27**	1.2**	0.52	6.13	11.72
15	SL	0.97^{ns}	9.05**	1.34**	0.33	7.55	4.19
16	SNPS	17.49**	52.00**	4.98**	1.90	21.61	6.38
17	KNPS	144.41^{ns}	1084.57**	59.01**	22.06	52.49	8.95
18	SW	1.93**	1.55**	0.14**	0.05	3.17	7.29
19	KWPS	O.838**	1.06**	0.087*	0.04	2.75	7.59
20	KPC	67.43**	12.29**	1.23^{ns}	1.27	12.36	9.11

ψ = Numbers in parenthesis represent degrees of freedom; ** Significant difference at ($p < 0.01$); * Significant difference at ($P < 0.05$); ns- non significant
DF-Days to flowering (days); DM- Days to maturity (days); GFP -grain filling period (days); HLW -Hectoliter weight (kg/hl); GY-Grain yield (kg ha^{-1}); BMY-Biomass yield (kg ha^{-1}); HI-Harvest index; BMPR -Biomass production rate (kg ha^{-1} day^{-1}); GSFR-Total grain sink filling rate (kg ha^{-1} day^{-1}); SGSFR -Spike grain sink filling rate (mg spike^{-1} day^{-1}); TPP -Tillers per plant (No.); SPP- Spikes per plant (No.); PH-Plant height (cm), SL -Spike length (cm); SW -spike weight (g); KWPS-kernel weight per spike (g); KNPS -kernel number per spike (No); TKW -Thousand kernel weight (g); SNPS -Spikelet number per spike (No.); KPC- Kernel Protein content

Generally, mean values of the varieties recorded in this study were also within the range of barley yield potential performance described in similar studies. Martiniello *et al.* (1987) indicated that breeding progress in winter barley breeding resulted in grain yield ranging from 4420.0 kg ha^{-1} to 7520.0 kg ha^{-1} in different barley genotypes in Italy. Yield potential of barley varies from state to state in America ranging from 1451.0 to 5499.0 kg ha^{-1} and barley yield of ten top leading producing countries is within the range of 1730.0 to 5470.0 kg ha^{-1} (Hockett, 2000). Beratto (2001) also reported similar progress from barley breeding in Chile, indicating yield potential of commercial seed producers increased from 2200.0 kg ha^{-1} in 1978 to 5700 kg ha^{-1} in 1997. Likewise, barley breeding contributed to grain yield improvement from 3636.0 kg ha^{-1} in 1973 to 8056.0 kg ha^{-1} in 2000 in Ecuador (Chicaiza, 2001). Moreover, assessment of genetic progress from barley breeding in Nordic spring barely breeding reported by Ortiz *et al.* (2002) that grain yield increased ranging from 2723.0 kg ha^{-1} to 4291.0 kg ha^{-1} in six row barley and 4140.0 kg ha^{-1} to 4583.0 kg ha^{-1} in two row barley genotypes. Abeledo *et al.* (2003) also revealed similar finding that yield potential improvement among varieties of barley varied from 5100.0 to 6700.0 kg ha-1 in Argentina.

There were significant (P< 0.01) differences among varieties in biomass yield and harvest index at all locations (Table 3). The mean above ground biomass yield ranged from 11506.0 kg ha^{-1} for Misrach to 16480.0 kg ha^{-1} for HB-1307 at Holetta, 8425.0 kg ha^{-1} for Ahor 880/61 to13287.5 kg ha^{-1} for Dimtu at Adadi and 7663.0 kg ha^{-1} for Abay to 13700.0 kg ha^{-1} for Balami at Jeldu. Varietal difference in biomass yield was less marked at Holetta than the rest of the locations may be owing to better adaptation of all varieties to the growing conditions at Holetta. The recent varieties (Dimtu and HB-1307) which gave high grain yield were also characterized by high biomass yield at all locations except HB-1307 at Holetta. However, overall mean biomass yield of the varieties were found to be non-significant.

This finding is in agreement with Ortiz *et al.* (2002) that there was no significant trend in straw yield in Nordic spring barley. The site mean harvest index also ranged 24.5% for Balami to 40.6% for Misrach at Holetta, 27.4% for Balami to 45.6% for HB-1307 at Adadi and 25.4% for Balami to 50.1% for Misrach at Jeldu. Varietal difference for harvest index was less marked at Jeldu than Adadi and Holetta. The overall mean harvest index in this study varies from 26% for Balami to 44% for Misrach, indicating the modern varieties showed significant improvement in harvest index.

Table 3. Mean grain yield, biomass yield and harvest index of food barley varieties at each location and over locations

	Locations											
	Holetta			Adadi			Jeldu			Mean		
Varieties	GY	BMY	HI	GY	BMY	HI	GY	BMY	HI	GY	BMY	HI
Balami	3637.0d	14834.0ab	24.5d	2960.0de	10812.5bc	27.4c	3347.5cd	13700.0a	25.4b	3314.8e	13115.3	25.8d
IAR/H/485	4073.3bcd	14895.0ab	27.2cd	3716.2dc	10875.0bc	34.2b	3062.4d	11900.0ab	25.8b	3617.3e	12556.7	29.0d
Ahor 80/61	5104.9ab	15179.0ab	34.2ab	2812.2e	8425.0d	33.0b	3465.6bcd	8450.0bc	41.9a	3794.3de	10684.5	36.4c
HB-42	3940.6cd	14538.0ab	27.1cd	4087.9bc	11625.0ab	35.1b	3612.5abcd	7738.0c	48.1a	3880.3cde	11300.2	36.8c
Ardu12-60B	4855.5abc	15689.0ab	31.8bc	4009.8bc	10750.0bc	37.3b	4568.1abc	10388.0abc	44.4a	4477.8abc	12258.9	37.8bc
Shege	5217.6a	16150.0ab	32.3bc	3997.5bc	9137.5cd	43.6a	3976.0abcd	8500.0bc	47.3a	4397.0bcd	11262.5	41.1ab
Abay	4803.9abc	13412.0c	35.9ab	4586.7abc	12712.5ab	36.0b	3625.5abcd	7663.0c	47.5a	4338.7bcd	11262.3	39.8bc
Misrach	4669.5abc	11506.0d	40.6a	4760.0ab	11275.0abc	42.2a	3971.1abcd	8025.0c	50.1a	4466.9abc	10268.8	44.3a
Dimtu	5174.3a	15863.0ab	32.7bc	4667.8ab	13287.5a	35.2b	4921.3ab	11424.0abc	43.1a	4921.1ab	13524.6	37.0c
HB-1307	5256.6a	16480.0a	32.8bc	5017.6a	11062.5bc	45.6a	4991.5a	11138.0abc	46.02a	5088.6a	12893.3	41.5ab
Mean	4673.3	14854.48	31.89	4061.58	10996.25	36.96	3954.15	9887.38	41.97	4229.68	11912.7	36.94
CV (%)	13.78	12.01	13.32	14.02	12.32	7.49	22.46	23.56	13.70	16.88	15.70	3.29
R^2	0.56	0.59	0.63	0.72	0.65	0.84	0.52	0.60	0.77	0.64	0.78	0.83

Means followed by a common letters with in a column are not significantly different from each other at P≤ 0.05 according to Duncan Multiple Range Test;
GY- Grain yield (kg ha^{-1}); BMY- Biomass yield (kg ha^{-1}); HI- Harvest index (%)

Similar result was reported by Martiniello *et al*. (1987) that harvest index increased from 42% in the genotype from the old population to 54% in the modern six row barley genotypes. They further noted that gain in grain yield of six row barley has been obtained by improving the harvest index rather than the biomass yield. In agreement with this finding; Wych and Rasmusson (1983), Riggs *et al*. (1981) and Ortiz *et al*. (2002) reported that modern barley varieties showed improved harvest index. Overall mean of varieties were significantly different for time to reach flowering, physiological maturity, total grain sink filling rate and spike grain sink filling rate (Table 4). Misrach reach earlier to flower followed by Abay and HB-1307, whereas the Ahor 880/61 delayed by about twenty six days. Similarly, Misrach was earlier than Ahor 880/61 by 39 days to reach physiological maturity followed by Abay, Balami, Shege and HB-1307. Besides, the highest total grain sink filling rate was obtained by HB-1307, thought it was at par with the varieties released since 1986.

Table 4 . Mean values of phenological growth traits of food barley varieties combined over locations

	Agronomic traits					
Variety	DF	DM✡	GFP✡	BMPR	GSFR	SGSFR✡
Balami	95.00d	149.08e	54.08	87.75	65.37c	39.48e
IAR/H/485	97.00b	153.50b	56.50	82.07	70.87c	50.04cd
Ahor 880/61	108.17a	170.83a	62.67	62.89	64.48c	53.22bcd
HB-42	95.92c	151.92bcd	56.00	75.74	75.98bc	49.19d
Ardu-12-60B	97.08b	152.17bc	55.08	81.07	87.04ab	56.16ab
Shege	95.58dc	150.42cde	54.83	74.46	84.94ab	56.27ab
Abay	90.00e	143.75f	53.75	80.33	86.46ab	53.95bc
Misrach	82.42f	131.17g	48.75	79.41	92.42a	59.46a
Dimtu	95.58dc	153.17b	57.58	90.07	92.89a	53.31bcd
HB-1307	90.33e	149.92de	59.58	86.47	93.01a	53.24bcd
Mean	94.71	150.59	55.88	80.03	81.35	52.43
CV (%)	0.99	0.32	1.06	15.50	16.93	8.99
R^2	0.99	0.99	0.98	0.78	0.83	0.92

Means followed by a common letters with in a column are not significantly different from each other at
$P \leq 0.05$ according to Duncan Multiple Range Test; DF-Days to flowering (days); DM- Days to maturity (days); GFP -grain filling period (days); BMPR -Biomass production rate (kg ha^{-1} day^{-1}); GSFR-Total grain sink filling rate (kg ha^{-1} day^{-1}); SGSFR -Spike grain sink filling rate (mg $spike^{-1}$ day^{-1}); ✡= log transformation

Generally, the newly released varieties showed relatively higher total grain sink filling rate than the old varieties. Furthermore, Misrach showed significantly high spike grain sink filling rate though it was at par with Ardu-12-60B and Shege, whereas farmers' variety Balami gave the lowest mean value for this trait. In this study, grain filling duration and above ground biomass production rate were found to be non-significant. Generally, these results were in agreement with work of Martiniello *et al*. (1987) that the modern genotypes showed a trend toward earliness in both six and two row barley genotypes compared to the oldest ones. Most of modern barley varieties were relatively earlier than the older varieties whereas maturity time was similar for all the varieties (Wych and Rasmusson, **1983)**.

Overall mean values of yield components are shown in Table 5. There were significant ($P<0.01$) differences among food barley varieties for all the agro-morphological traits under consideration. The local farmers' variety Balami gave significantly highest thousand kernel weight followed by the recently released varieties Shege, Dimtu and HB-1307, whereas Abay was characterized with the lowest thousand kernel weight. The highest mean value of this trait in Balami seems to be compensation effect of lowest kernel number per spike.

Table 5. Mean values of yield components of food barley varieties combined over locations

	Agronomic traits										
Variety	TKW	HLW	PH	TPP	SPP	SL✡	SNPS	KNPS	KWPS	SW	KPC
Balami	54.06a	65.53bc	120.59ab	7.15abc	5.60d	8.35a	21.79bc	27.40f	2.02e	2.32f	13.97a
IAR/H/485	44.17d	65.77b	122.76a	7.26ab	5.98cd	7.58cd	21.29cd	51.58de	2.64cd	3.02de	12.18cde
Ahor 880/61	45.67c	64.28cd	104.38d	5.66e	4.75e	5.47e	27.05a	61.61a	3.11a	3.68a	10.27f
HB-42	44.64dc	65.89b	120.51ab	6.61bcd	6.35bc	7.11d	19.44e	49.93e	2.59d	2.98e	12.51bcde
Ardu-12-60B	44.61dc	67.68a	121.59ab	6.44dc	6.22bcd	7.60cd	20.75cd	55.34cd	2.87b	3.31bc	11.84de
Shege	47.90b	63.53d	109.92c	6.55bcd	6.29bc	7.82bc	20.79cd	54.79cd	2.91b	3.41b	13.28ab
Abay	39.27e	59.64e	108.81c	7.47a	7.26a	8.58a	22.51b	59.96ab	2.75bcd	3.21bcd	12.76bcd
Misrach	45.80c	65.48bc	102.99d	6.59bcd	6.25bcd	5.57cd	21.24cd	56.51bc	2.89b	3.29bc	12.35bcde
Dimtu	47.88b	65.55bc	117.82b	6.05de	5.91cd	8.17ab	20.94cd	52.47cde	2.79bc	3.15cde	12.92bc
HB-1307	47.70b	66.00b	103.72d	6.93abc	6.71ab	7.25d	20.26de	55.36cd	2.94b	3.31bc	11.56e
Mean	46.17	64.94	113.31	6.67	6.13	7.55	21.61	52.49	2.75	3.17	12.36
CV (%)	3.4	2.51	3.89	11.82	11.72	4.19	6.38	8.95	7.59	7.29	9.11
R^2	0.93	0.79	0.87	0.69	0.71	0.81	0.79	0.87	0.79	0.83	0.74

Means followed by a common letters with in a column are not significantly different from each other at $P\leq 0.05$ according to Duncan Multiple Range Test;
TKW -Thousand kernel weight (g); HLW -Hectoliter weight (kg/hl); PH-Plant height (cm); TPP -Tillers per plant (No.); SPP- Spikes per plant (No.);
SL -Spike length (cm); SW -spike weight (g); KWPS-kernel weight per spike (g); KNPS-kernel number per spike; SNPS -Spikelet number per spike;
KPC- Kernel Protein content; ✡= log transformation

The highest hectoliter weight was recorded for Ardu-12-60B and the lowest for Abay. Yet, clear trend of improvement was not observed for this trait. Significant improvement in reducing plant height was observed from about 123 cm for the earlier variety IAR/H/485 to 103 cm for HB-1307. Relatively, modern varieties showed declining trend in plant height as compared to the oldest varieties. Besides clear trend of improvement in tiller per plant was not detected while relative improvement in spike per plant was observed. The highest and lowest mean values for tiller per plant, fertile spike per plant and spike length was obtained by Abay and A hor 880/61, respectively. A hor 880/61 variety was characterized by lowest spike length, high kernel number per spike with small size, high spikelet number per spike, high kernel weight per spike and high spike weight even though potential of these traits in this variety was not reflected on thousand kernel weight, hectoliter weight and grain protein content. Balami was characterized with low spike weight, low kernel number per spike and low kernel weight per spike. Furthermore, there was significant ($P< 0.01$) difference in grain protein content among food barley varieties with the highest value for Balami and Shege whereas the lowest for A hor 880/61. On the other hand, HB-1307 variety has showed low protein content, accompanied with optimum thousand kernel weight and good kernel plumpness in this variety seems to satisfy malt quality standard. Hence, it might be used as a donor parent in malting barley crossing work.

Generally, several researchers investigated trends in different barley types for their yield components. Riggs *et al*. (1981) revealed that a greater efficiency in the utilization of assimilates for grain filling as indicated by their greater tiller survival in modern varieties. According to Martiniello *et al*. (1987) modern six-row barley varieties have shown consistent increase in tiller per meter square and seed per spike over the local population, while in modern two row varieties, tiller per meter square and seed weight increased with decreasing trend in seed per spike. Moreover, they further revealed that modern six and two row barley varieties have shorter stature than the old varieties and local populations. Similarly, Ortiz *et al*. (2002) reported significant reduction in plant height. Furthermore, it was shown that barley breeding progress resulted in substantial improvement of thousand kernel weight in six-row and hectoliter weight in two row varieties.

In Nordic barley breeding hectoliter weight and thousand-kernel weight were significantly improved in six row barley cultivars (Ortiz *et al.,* 2002). Testing sites were notably ($P< 0.01$) different for all the agronomic traits considered except spike length and kernel number per spike. The highest grain yield, biomass yield, spike weight and kernel protein content were obtained at Holetta. Moreover, Holetta took long days to flowering flowed by Jeldu and long days to physiological maturity was at Jeldu followed by Holetta. Similarly, the highest mean value for total grain sink filling rate and spike grain sink filling rate were recorded at Adadi followed by Holetta whereas biomass production rate at Holetta was similar to that of Adadi (Table 8).

Genetic Progress from Breeding

Grain yield

The ten food barley varieties grown in yield potential trials represent the period from 1970s to 2000s, out of which more than half of the varieties were derived from landrace selection. The mean grain yield ranged from 3314.8 kg ha^{-1} for Balami to 5088.6 kg ha^{-1} for HB-1307 barley varieties. Generally mean of individual varieties across locations showed that there was gradual increase in grain yield parallel with year of release of the varieties. The average grain yield of varieties released in 1970s, 1980s, 1990s and 2000s were 3617.27, 4050.81, 4400.87 and 5004.83 kg ha^{-1}, respectively. This indicated an increase of 302.44 (9%), 735.98 (22%), 1086.04 (33%) and 1690.00 (51%) kg ha^{-1} over the farmers' variety Balami. Similarly 12%, 22% and 38% yield increment was shown over the oldest improved variety IAR/H/485. Concurrence to this finding Amsal (1994) reported achievement in highest grain yield of modern varieties of bread wheat with yield of 6610 kg ha^{-1} at Holetta and 4820 kg ha^{-1} at Kulumsa showing an increase in yield potential of 89% and 71%, respectively. Similarly, Perry and D'Antuono (1989) in wheat found substantial increase of modern varieties over the older ones.

The annual rate of gain in yield potential was estimated from linear regression of mean grain yields of varieties on year of release expressed as the number of years since 1970s, the period when coordinated barley breeding program started (Table 6). Empirical experimental evidence of gains in barley yield showed that an average rate of increase in yield potential per year of release over 36 years period from the slope of linear regression shown in the graph was 44.24 kg ha^{-1} (1.34%) year^{-1} over the dominant farmers' variety Balami. When 1975 was considered as a base year (during which the first food barley variety released), the annual rate of increase in grain yield potential was 42.96 kg ha^{-1} year^{-1} (Figure 1A and B).

Table 6 . Estimates of mean values, correlation coefficient, constant, and regression (b) of various morpho-agronomic traits of Barley varieties means on year of release

Traits	Overall Mean	Mean of *Balemi*	Intercept/ Constant	Regression (b) Since		RGG (% yr-1)	Correlation coefficient with year of release
				1970	1975		$r_{(yor)}$
Days to flowering	94.71	95.00	100.41	-0.301	-0.43	-0.32	-0.54
Days to maturity	150.59	149.08	156.9	-0.325	-0.52	-0.22	-0.41
Grain filling period	55.88	54.08	56.49	-0.034	-0.09	-0.06	-0.11
Thousand kernel weight	46.17	54.06	47.86	-0.093	0.07	-0.15	-0.26
Hectoliter weight	64.94	65.53	65.79	-0.043	-0.05	-0.07	-0.24
Biomass Yield	11912.7	13115.33	12041	-6..58	19.81	-0.05	-0.06
Grain Yield	4229.67	3314.83	3366.97	44.24**	42.96**	1.34	0.94**
Harvest index	0.37	0.26	0.29	0.004**	0.003**	1.58	0.85**
Biomass production rate	80.03	87.75	77.32	0.149	0.39	0.17	0.23
Total grain sink filling rate	81.35	65.37	64.69	0.85**	0.87**	1.33	0.91**
Spike grain sink filling rate	52.43	39.48	46.42	0.31*	0.14	0.79	0.67*
Plant height	113.31	120.59	120.93	-0.391*	-0.39	-0.33	-0.58*
Tillers per plant	6.67	7.15	6.74	-0.004	0.006	-0.04	-0.07
Spikes per plant	6.13	5.6	5.49	0.033	0.04	0.59	0.59*
Spike length	7.55	8.35	7.28	0.014	0.04	0.18	0.21
Spikelet number per spike	21.61	21.79	22.63	-0.052	-0.07	-0.25	-0.31
kernel number per spike	52.49	27.4	43.86	0.44	0.04	1.61	0.54
Spike weight	3.17	2.32	2.88	0.014	0.001	0.6	0.47
kernel weight per spike	2.75	2.02	2.47	0.014	0.003	0.69	0.56
Kernel protein content	12.36	13.97	12.43	-0.004	0.03	-0.02	-0.03

*, ** *b* values were significantly different from zero at the probability of 0.05 and 0.01 respectively and r values were significant at 0.05 and 0.01, respectively

Likewise, increase in yield potential since 1980 was 43.03 kg ha^{-1} $year^{-1}$ and since 1985 when HB-42 was developed through crossing was 41.48 kg ha^{-1} $year^{-1}$. If estimation is made from equation Y= 44.241X + 3367, the estimated grain yield at initial year (1970) was 3367 kg ha^{-1} compared with 3809 kg ha^{-1} at 10 years (1980), 4252 kg ha^{-1} at 20 years (1990), 4694 kg ha^{-1} at 30 years (2000). These confirmed endeavor of Ethiopian barley breeders to improve yield potential of food barley through exploitation of available genetic variability in the country and international germplasm exchange. These linear increases in different decades demonstrated that a yield plateau has not reached in barley improvement in Ethiopia.

Similarly, Riggs *et al*. (1981) reported genetic gain of 0.39% $year^{-1}$ during 100 years and 0.84% $year^{-1}$ during 28-years barley breeding periods. In Italy barley grain yield has increased by 52 and 54 kg $ha^{-1}year^{-1}$ or 0.75% and 1.1% per year respectively for six and two row genotypes (Martiniello *et al*., 1987). The absolute gain in yield was at the yearly rate of 13 kg ha^{-1} for two row barley varieties and 22 kg ha^{-1} in six row barley varieties in Nordic spring barley breeding with the relative genetic gain ranging from 7% to 172% (Ortiz *et al*., 2002). Regression analysis of six barley cultivars in USA indicated that breeding efforts in the forty years time period, yield gains have been nearly linear with the slope of 45.7 kg ha^{-1} (2%) $year^{-1}$ (Wych and Rasmusson, 1983). Similarly, barley breeding consistently increased grain yield with genetic gains of 16 kg ha^{-1} $year^{-1}$ in the USA (Boukerrou and Rasmusson, 1990). According to Beratto (2001) barley breeding within a 63 year period in Chile was equal to yield gain of 149.3% or an annual increase of 34.6 kg ha^{-1}. Likewise, barley yield potential improvement in Argentina increased at a rate of 41 kg ha^{-1} $year^{-1}$ since 1970's (Abeledo *et al*., 2003). Similar study in Canada showed that grain yields of barley varieties released from 1935 to 1988 increased at a rate of 30 kg ha^{-1} $year^{-1}$ (Bulman *et al*., 1993).

Harvest index and Biomass yield

It was shown from analysis of variance that varieties were markedly (P< 0.01) different from each other in harvest index. Improved varieties have high harvest index compared to the local variety Balami. An increase which is greater than 16 units of percent in harvest index was achieved when the oldest varieties compared with the newest once. Similarly, linear regression coefficient indicated that harvest index showed a positive and significantly different from zero (P< 0.01) with year of release of the varieties. The average rate of increase in harvest index was also 0.004 $year^{-1}$and the progress occurred at annual rate of 1.58% increase for the last three decades (Table 6). This shows breeding for increased genetic yield potential of food barley was attributed to improved dry matter partitioning capacity in Ethiopia. In line with this result, Riggs *et al*. (1981) revealed that newer spring barley varieties developed in England and Wales between 1880 and 1980, showed shorter straw and higher harvest index with regression slope of 0.0013. Wych and Rasmusson (1983) also reported similar finding that genetic improvement in barley varieties since 1990 was owing to improvement in harvest index from 31% to 40%. According to Ortiz *et al*. (2002) improvement in harvest index was 0.0008 $year^{-1}$ in two row and 0.0018 $year^{-1}$ in six row barely genotypes. Nonetheless, Abeledo *et al*. (2003) in barley found that harvest index was not steadily modified with the year of release of the varieties.

On the other hand, it was witnessed by other authors that grain yield improvement was parallel with increase in harvest index and biomass yield. Martintello *et al*. (1987) reported that gain in biomass yield was not uniform for six row varieties while that of two row barley varieties increased by 64 kg ha^{-1} (0.46%) $year^{-1}$. Likewise, it was indicated in similar study that in spring barley increase in yield was associated with higher total dry matter production and harvest index, and reduced plant height (Bulman *et al*., 1993).

Likewise, linear regression coefficient also depicted that biomass yield did not change significantly during the past barley breeding activities in the country (Table 6). In line with this finding, Ortiz *et al*. (2002) reported non significant trend in straw yield in spring barley breeding. Similarly, there was no discernible improvement in biomass yield of bread wheat and durum wheat breeding **in** Ethiopia (Amsal, 1994). Contrary to this result, in the biomass (45 kg ha^{-1} $year^{-1}$) and vegetative biomass (19 kg ha^{-1} $year^{-1}$) at maturity was found that the rate of biomass gain has been similar to that of yield gain (Abeledo *et al*., 2003). Likewise, Boukerrou and Rasmusson (1990) reported that in spring barley breeding total biomass and vegetative biomass (straw yield) increased at a rate of 22.5 and 6.8 kg ha^{-1} $year^{-1}$ respectively.

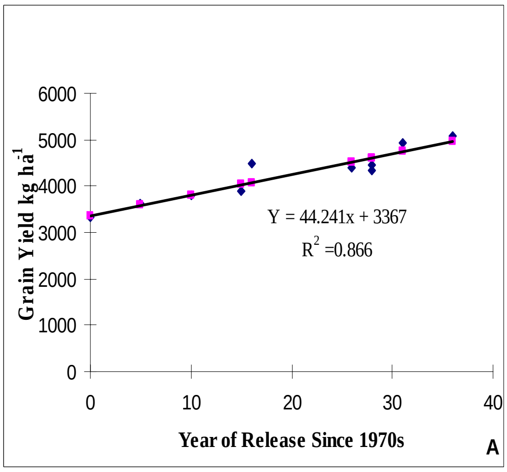
Phenological Development

The modern varieties relatively took intermediate to short days to reach flowering and physiological maturity. However, there was no evidence for change among varieties with respect to grain filling period. Despite significant variation in phenological development phases, regression of phenological growth traits such as days to flowering, days to maturity and grain filling period showed slopes with negative trend but not significantly different from zero. Concurrence to this result, Ortiz *et al*. (2002; Abeledo *et al*. (2003) reported non- significant trend in days to flowering and maturity. Nonetheless, Cox *et al*. (1988), Perry and D'Antuono (1989) indicated that modern study of genetic improvement of two row malting barley yield potential in Argentina, total

wheat varieties were earlier maturing than the oldest ones.

Biomass Production and Grain Filling Rates

The mean for biomass production rate showed that there was no discernible difference between varieties. Similarly, regression of biomass production rate on year of release of the varieties has showed no indication of improvement in this trait (Table 6). Amsal (1994) in his study of biomass production rate in wheat also found that genetic yield potential improvement had little effect on biomass production rate over 38 years period of wheat breeding. Total grain sink filling rate on the other hand showed significant mean difference among varieties. There was also significant and positive trend with an average annual increase of 0.85 kg ha^{-1} day^{-1}(1.33% $year^{-1}$). Likewise, the average annual increase in spike grain sink filling rate from linear regression of mean rates on year of release was 0.31 mg $spike^{-1}$ (0.8%) day^{-1}. In line with this finding, Amsal (1994) indicated substantial improvement in spike grain sink filling rate in bread wheat.



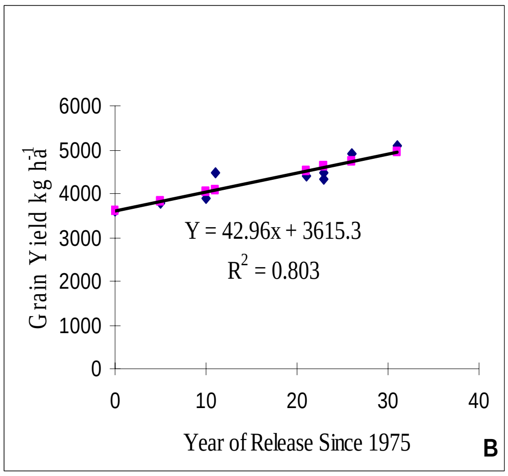


Figure 1. Plot of grain yield of food barley varieties against years of release of varieties; Since 1970 (A) the period when coordinated barley breeding was started based on Balami; since 1975 (B) the year when the first improved variety IAR/H/485 was released;

Yield Components and other Agronomic Traits

Mean performance of plant height showed significant (P<0.01) difference among the varieties that the recent varieties being relatively shorter than the older ones. Plant height reduced by about ten to twenty centimeter disregarding Dimtu. Significant (P<0.05) negative trend on year of release was obtained from regression line with an average annual genetic gain of - 0.39 cm (-0.33%) year^{-1} indicating barley breeders have selected short stature genotypes which are lodging resistant and this might contributed for increased harvest index and grain yield in food barley improvement. In line with this result, Ortiz *et al.* (2002) indicated that improvement in yield was achieved in Nordic barley by reducing plant height by 0.2 cm year^{-1} for two-row and 0.16 cm yr^{-1} for six row varieties. In the same way, Donmez *et al.* (2001) reported similar finding that modern varieties showed significantly decreased plant height and reduced lodging in winter wheat varieties. On the other hand, mean spike length exhibited significant (P< 0.01) difference among varieties despite the fact that there was no evidence of clear trend with year of release of the varieties. In similar way, mean thousand seed weight, hectoliter weight and kernel protein content showed significant differences among the varieties, though there was no significant progress noticed with year of release of the varieties. Barley varieties revealed significant variation in number of tiller per plant with negative trend with year of release, though regression slope was not significantly different from zero. Number of spike per plant (effective tillers) also showed significant difference among the varieties with relative improvement in the modern varieties as compared to the oldest ones, thought there was no significant trend with year of varietal release. Generally, food barley varieties demonstrated significant difference for some other traits such as; spikelet number per spike, kernel number per spike, kernel weight per spike and spike weight with no marked trend of improvement with year of release. However, Ortiz *et al.* (2002) indicated that improvement in yield was achieved in Nordic barley through significantly enhancing thousand kernel weights by 0.07 g year^{-1} and hectoliter weight by 0.06 kg hl^{-1} year^{-1} in two and six row barley genotypes respectively.

Agro-morphological Traits Associated with Yield Potential Improvement

Selection criteria take into account the information on interrelationship among agronomic characters, their relationship with grain yield as well as their direct influence on grain yield. There was positive correlation between grain yield, harvest index, spike grain sink filling rate, total grain sink filling and spike per plant with year of release of the varieties, whereas plant height was negatively associated with year of release indicating substantial progress in barley improvement with respect to these traits(Table 6). The relative value of genetic gain in grain yield (1.34%) year $^{-1}$ was strongly (r= 0.77, P<0.01) related with harvest index whereas there was no significant association between grain yield and biomass yield. Moreover, harvest index showed significant positive association with total grain sink filling rate, spike grain sink filling rate, kernel number per spike, kernel weight per spike and spike weight, but negatively associated (r = -0.7, P < 0.05) with plant height (Table 7).

Wych and Rasmusson (1983), Martiniello *et al.* (1987), and Ortiz *et al.* (2002) in barley Perry and D'Antuono (1989) in wheat, reported that gain in grain yield potential of modern varieties was largely attributed to improvement in harvest index. Ortiz *et al.* (2002) further noted that grain yield gain in new varieties of barley was associated with more spikes (fertile tillers) per unit area, superior lodging resistance and better adaptation to modern cultural practices. Nonetheless, Abledo *et al.* (2003) indicated that increases in grain yield of barley were associated mainly with biomass.

Table 7. Estimates of correlation coefficient among morpho-agronomic traits of barley varieties means over Holetta Adadi and Jeldu test locations

	DF	DM	GFP	TKW	HLW	GY	BMY	HI	BMPR	GSFR	SGSFR	PH	SPP	SL	SNPS	KNPS	KWPS	SW
DM	0.97**																	
GFP	0.79**	0.91**																
TKW	0.08	0.07	0.05															
HLW	0.11	0.11	0.09	0.47														
GY	-0.41	-0.27	0.02	-0.19	0.02													
BMY	0.08	0.15	0.26	0.47	0.37	0.13												
HI	-0.44	-0.37	-0.19	-0.43	-0.21	0.77**	-0.52											
BMPR	-0.53	-0.47	-0.31	0.32	0.23	0.31	0.79**	-0.22										
GSFR	-0.67*	-0.58	-0.34	-0.24	-0.02	0.93**	0.06	0.77**	0.43									
SGSFR	-0.27	-0.24	-0.16	-0.56	-0.11	0.68*	-0.51	0.88**	-0.29*	0.68								
PH	0.26	0.15	-0.05	0.15	0.40	-0.43	0.55	-0.70*	0.38	-0.32	-0.54							
SPP	-0.71*	-0.66*	-0.46	-0.48	-0.37	0.48	0.01	0.45	0.41	0.66*	-0.28	-0.08						
SL	-0.61	-0.65*	-0.63*	0.06	-0.25	0.15	0.42	-0.11	0.77**	0.39	-0.17	0.34	0.63*					
SNPS	0.59	0.57	0.47	-0.09	-0.34	-0.33	-0.36	-0.12	-0.64*	-0.52	0.01	-0.39	-0.64*	-0.59				
KNPS	0.04	0.11	0.21	-0.76**	-0.29	0.53	-0.52	0.74**	-0.49	0.43	0.87**	-0.54	0.20	-0.41	0.27			
KWPS	0.12	0.20	0.32	-0.5	-0.09	0.60*	-0.45	0.76**	-0.50	0.43	0.88**	-0.61	0.01	-0.54	0.29	0.94**		
SW	0.21	0.27	0.34	-0.52	-0.16	0.49	-0.53	0.72**	-0.62	0.33	0.85**	-0.61	-0.04	-0.58	0.39	0.94**	0.99**	
KPC	-0.44	-0.52	-0.61	0.38	-0.15	-0.14	0.34	-0.28	0.59	0.09	-0.41	0.42	0.34	0.86**	-0.56	-0.67*	-0.73**	-0.7**

*, ** r values were significant at probability level of 0.05 and 0.01 respectively; Ω refers to abbreviations:

On the other hand, the relative genetic gain of (1.33%) year^{-1} in total grain sink filling rate was strongly associated with grain yield and it was also positively associated with harvest index and spike per plant, but negatively correlated with days to flowering. Moreover spike grain sink filling rate and kernel weight per spike were significantly and positively correlated with gain yield. The association between spike grains sink filling rate with harvest index, kernel number per spike, kernel weight per spike and spike weight was markedly and positively significant (Table 7). Donmez *et al.* (2001) indicated that kernel number was positively correlated with grain yield, biomass yield, harvest index, spike length and spkelet number and negatively correlated with heading date in the study of genetic gain in winter wheat.

Stepwise regression analyses using grain yield as dependant variable indicated that, harvest index, biomass yield and biomass production rate were traits which contributed to gain in grain yield. Particularly, 46% of the variation in grain yield of food barley was explained by harvest index, 73% by biomass yield and harvest index altogether and 74% was contributed collectively by biomass yield, harvest index and biomass production rate. This illustrates that the improvement in grain yield was achieved by combination of different factors (Table 9).

Table 8. Mean performances of different agro-morphological traits of food barley varieties at the three test locations

Location	DF	DM	GFP	TKW	HLW	BMY	GY	HI	BMPR	GSFR	SGSFR
Holetta	104.25a	161.03b	56.77b	46.87b	65.93a	14854.5a	4673.3a	31.89c	92.24a	82.75b	50.89b
Adadi	88.22c	126.17c	38.55c	42.92c	63.42b	10996.3b	4061.6b	36.96b	87.33a	105.59a	67.33a
Jeldu	91.65b	163.97a	72.33a	48.73a	65.48a	9887.4c	3954.1b	41.96a	60.51b	55.69c	39.07c
Mean	94.71	150.59	55.88	46.17	64.94	11912.70	4229.68	36.94	80.51	81.34	52.43
CV (%)	0.99	0.32	1.06	3.40	2.51	15.70	16.88	3.29	15.51	16.94	2.46

Location	PH	TPP	SPP	SL	SNPS	KNPS	KWPS	SW	KPC
Holetta	114.75a	6.32b	5.83b	7.7	22.37a	54.59	2.87a	3.4a	13.83a
Adadi	116.51a	7.57a	6.79a	7.55	21.21b	50.9	2.59b	2.96c	11.36c
Jeldu	108.67b	6.12b	5.77b	7.39	21.24b	51.98	2.79a	3.13b	11.90b
Mean	113.31	6.67	6.13	7.55	21.61	52.49	3.17	2.75	12.36
CV (%)	3.89	11.82	11.72	4.19	6.38	8.95	7.29	7.59	9.11

Means followed by a common letters with in a column are not significantly different from each other at p ≤ 0.05 according to DMRT; Ω refers to abbreviation:

Table 9. Summary of selection from stepwise regression analysis of mean grain yield of food barley as dependant variable on independent variables

	Grain Yield				
	Independent variables	Intercept	Regression coefficient (*b*)	R^2	VIF
1	Biomass Yield		0.27	0.26	4.92
2	Harvest Index	-3774.79	105.10	0.73	1.62
3	Biomass Production Rate		11.10	0.74	4.25

** All regression coefficients are significant at P≤0.01; VIF: variance inflation factor

According to Amsal (1994) results of a stepwise regression analysis of grain yield on selected yield components revealed that number of grain per meter square alone accounted for most of the variation (>68%) in grain yield while number of gain per meter square, seed weight, plant height, biomass yield collectively contributed for more than 93% variation in wheat grain yield.

CONCLUSION

Efficient breeding program should successively release new crop varieties which are high yielding with pertinent quality standard. Evaluation of series of varieties from different years in a common environment is the most comprehensive and direct way that has been used to estimate progress in improving yield potential. Periodic evaluation of genetic improvement of crop varieties is required to understand the efficiency of past breeding activities in achieving genetic gain in grain yield and related traits to identify associated traits which are essential for further yield potential improvement. Study of yield potential improvement was conducted using ten food barley varieties to estimate progress made in grain yield and other agro- morphological attributes of food barley in Ethiopia.

The results of the study revealed that breeding has made substantial progresses over the past four decades in improving grain yield potential of barley varieties. Food barley grain yield has increased from 3314.8 kg ha^{-1} to 5088.6 kg ha^{-1}. Yield increment of modern varieties over the farmers' variety, Balami, was 1690 kg ha^{-1} (51%) whereas increment over the oldest improved variety, IAR/H/485 was 1388 kg ha^{-1} (38%). Based on regression of mean grain yield versus the number of years elapsed since the inception of coordinated barley breeding and since the first IAR/H/485 variety released, yield gain has risen at an average rate of 44.24 kg ha^{-1} (1.34%) and 42.96 kg ha^{-1} (1.19%) $year^{-1}$ respectively. Moreover, significantly increasing trend parallel to variety release was also evident for harvest index, total grain sink filling rate, spike grain sink filling rate and reduced plant height. On the other hand, the slopes days to flowering, days to physiological maturity and grain filling period were not significantly different from zero. Furthermore, stepwise regression analysis indicated that harvest index to be the most important character accounting for forty six percent of the variation in gain yield while harvest index, biomass yield, biomass production rate altogether contribute about 74% of the variation.

In this study, changes in food barley yield potential were strongly correlated with harvest index without change in biomass yield, indicating progressive improvement in harvest index was successful in developing varieties which are efficient in dry matter portioning. Moreover, grain yield was positively associated with total grain sink filling rate, spike grain sink filling rate and kernel weight per spike. Similarly year was significantly and positively correlated with gain in grain yield, harvest index, total grain sink filling rate, spike grain sink filling rate and spike per plant whereas plant height showed significant negative association with year.

In this study, absence of yield plateau indicated the potential for further progress in grain yield in barley. Future barley breeding work should focus on introduction of exotic materials and comprehensive crossing work at large. On the other hand, barley is not only needed for grain purpose but also for its straw yield. The issue of biomass yield improvement is also vital for prospective yield potential improvement, as harvest index for several cereal crops is approaching ceiling point. Hence, future breeding works need to take into account evaluation of materials for the biomass yield potential as well.

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REFERENCES

Abeledo, LG., DF. Calderini and Slafer, GA. 2003. Genetic improvement of barley yield potential and its physiological determinants in Argentina (1944-1998). Euphytica 130: 325-334.

Amsal Tarekegn, 1994. Yield potential of rain fed wheat in the central highland of Ethiopia. An MSc Thesis Presented to the School of Graduate Studies of Alemaya University. 151p.

Anderson, PM., EA. Oelke and Simmons, SR. 2002. Growth and development guide for spring barley. University of Minnesota. hattp://www.Extension/.umn.edu/.

Anonymous, 2002. SAS /STAT Guide for personal computers, version 9.0 editions. SAS Institute Inc., Cary, NC, USA.

Baye Mulat and Berhane Lakew. 2006. Barley research and Development in Ethiopia- an overview.. In: Mulatu B. and Grando S. (eds). Barley Research and Development in Ethiopia. Proceedings of the 2nd national barely research and development Review workshop. 28-30 November 2006, HARC, Holetta, Ethiopia.

Beratto, ME. 2001. Contributions of breeding and crop management to increasing barley yield and grain quality in Chile. pp. 10-16. In: Vivar H.E. and A. McNab (eds). Breeding barley in the new millennium: proceedings of an international symposium. Mexico, D.F.

Berhane Lakew, Hailu Gebre and Fekadu Alemayehu, 1996. Barley production and research. pp 1-8. In: Hailu Gebre and Joob Van Luer (eds). Barley Research in Ethiopia: Past work and future prospects. Proceedings of the first barley research review workshop 16-19, October. 1993. Addis Ababa, IAR/ICARDA. Addis Ababa, Ethiopia.

Birhanu Bekele, Fekadu Alemayehu and Berhane Lakew, 2005. Food barley in Ethiopia. pp. 53-82. In: Grando, Stefania and Helena Gomez Macpherson (eds). 2005. Food Barley: Importance, uses and local knowledge. Proceedings of the international workshop on food barley improvement, 14-17. January 2002, Hammamet, Tunisia. ICARDA.

Boukerrou, L. and Rasmusson, DD. 1990. Breeding for high biomass yield in spring barley. Crop Sci. 30: 31-35.

Bulman, P., DE. Mather and Smith, DL. 1993. Genetic improvement of spring barley cultivars grown in eastern Canada from1910 to 1988. Euphytica. 71:35-48

Burger, WC. and LaBerge, DE. 1985. Malting and brewing quality. pp. 367-398. In: Donald C. Rasmusson (ed). Barley. Agronomy 26. American Society of Agronomy, Inc.

Ceccarelli, S., S. Grando, V. Shevostove, H.Vivar, A.Yahyaoui, M. El-Bhoussini and Baun, M. 1999. ICARDA Strategy for global barley improvement. RACHIS .18:3-12.

Chicaiza, O. 2001. Impact of ICARDA/CIMMYT barley germplasm on barely breeding in Ecuador. pp. 25-27. In: Vivar H.E. and A. McNab(eds). Breeding barley in the new millennium: Proceedings of an international symposium. Mexico, D.F. CIMMYT.

CSA, 2010. Area and production of crops (private peasant holdings, Meher Season). Statistical Bulletin. Addis Ababa, Ethiopia

CSA. 2008. Area and production of crops: Private peasant holders, Belg season. Statistical Bulletin, Addis Ababa Ethiopia

Cox, T.S., J.P. Shroyer, Liu Ben-Hui, R.G. Sears and Martin, TJ. 1988. Genetic improvement in agronomic traits of winter wheat cultivars from 1919 to 1987. Crop Sci. 28:756-760.

Donmez, E., RG. Sears, JP. Shroyer and Paulesen, GM. 2001. Genetic gain in yield attributes of winter wheat in the Great Plains. Crop Sci. 41:1412-1419.

Evans, LT. and Fischer, RA. 1999. Yield potential: its definition, measurement, and significance. Crop Sci. 39:1544-1551.

Gemechu Keneni, 2007. Phenotypic diversity for biological nitrogen fixation in Abyssinian field pea (Pisum sativum var. abyssinicum) germplasm accession. Report on independent study for PhD. Addis Ababa University Science Faculty.

Girma Getachew, Abate Tedila, Seyum Bediye and Amaha Sebsibe, 1996. Improvement and utilization of barley straw. pp 171-181. In: Hailu Gebre and Joob Van Luer (eds). Barley Research in Ethiopia: Past work and future prospects. Proceedings of the 1st barley research review workshop 16-19 October. 1993. Addis Ababa, IAR/ICARDA.

Gomez, KA. and Gomez, AA. 1984. Statistical procedure for agricultural research. Second edition. International Rice Research Institute. John Wiley and Sons Inc.

Hailu Gebre, Berhane Lakew, Fekadu Fufa, Berhanu Bekele, Alemayehu Asefa and Tesfaye Getachew, 1996. Food barley breeding. pp. 9-23. In: Hailu Gebre and Joob Van Luer (eds). Barley Research in Ethiopia: Past work and future prospects. Proceedings of the 1st barley research review workshop 16-19oct. 1993. Addis Ababa, IAR/ICARDA. Addis Ababa, Ethiopia.

Harlan, JR. 1976. Barley. pp. 93-98. In: Evolution of crop plants. NW. Simmonds (ed).Longman Press. UK.

Hockett, E.A. 2000. Barley. In Kulp, K. and Joseph, G.P. (eds). Handbook of cereal science and technology. 2nd ed. Marcel Dekker, Inc. New York.

Hockett, EA. and Nilan, RA. 1985. Genetics. pp 187- 230. In: Rasmusson, Donald C. (ed.) Barley. Agronomy 26. American Society of Agronomy, Inc.

IPGRI, 1994. Descriptors for barley (Hordeum vulgare L.). International plant genetic resource institute, Rome, Italy.

Martin, JH., RP. Walden and Stamp, DL. 2006. Principle of field crop production. Pearson Education, Inc. USA.

Martintello, P., G. Delocu, G. Boggini, M. Odoardi and Stanca, AM. 1987. Breeding progress in grain yield and selected agronomic characters of winter barley (Hordeum vulgare L.) over the last quarter of a century. Pla.. Br. 99:289–294.

Mason, RL., FG. Richard and James, LH. 2003. Statistical design and analysis of experiments with applications to engineering and science. 2nd Edition. John Wiley and Sons, Inc. Canada.

Ortiz, R., M. Nurminiemi, S. Madsen, O.A. Rognli and Bjornstad, A. 2002. Genetic gains in Nordic spring barley breeding over sixty years. Euphytica. 126: 283-289.

Perry, MW. and D'Antuono, MF. 1989. Yield improvement and associated characteristics of some Australian spring wheat cultivars introduced between 1860 and 1982. Aust. J. Agric. Res. 40:457-72.

Riggs,TJ., PR. Hanson, ND. Start, DM. Miles, CL. Morgn and Ford, MA. 1981. Comparison of spring barley varieties grown in England and Wales between 1880 and 1980. J. Agric. Sci. 97:599-610.

Waddington, SR. SR. Ransom, M. Osamanzi and Sounders, DA. 1986. Improvement in the yield potential of bread wheat adapted to NW Mexico. Crop Sci. 26:699-703.

Wych, RD. and Rasmusson, DC. 1983. Genetic improvement in malting barley cultivars since 1920. Crop Sci. 23:1037-1040.

Zemede Asfaw, 2000. The Barley of Ethiopia.pp 77-108. In: Stephen B. Brush(ed). Genes in the Field: On farm Conservation of Crop Diversity. IDRC/IPGRI.