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Genetic Gain in Grain Yield Potential and Associated Agronomic Traits in Haricot Bean (*Phaseolus vulgaris* L.)

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ABSTRACT

A yield potential experiment was conducted with 16 haricot bean varieties (10 released and 6 elite lines) developed by Ethiopian bean breeding program from 1972 to 1998 along with one local check (farmers' variety). The objectives were to understand the genetic gain made in grain yield potential and to determine changes produced on agronomic traits associated with genetic yield potential improvement. The varieties were evaluated in RCB design at Awassa Agricultural Research Center experimental field to estimate the genetic gain in grain yield and the other fifteen agronomic traits.

The analysis of variance revealed significant difference among varieties for all traits except the harvest index. The overall increase in grain yield over the local check, Red Wolayta, was estimated to be 1,604 kg/ha (82.4%). Based on the regression analysis, the estimated average annual rate of increase in grain yield potential was 69.45 kg/ha/year with an annual relative genetic change of 3.24%/year. Genotypic change was an important source of increased grain yield potential during the period studied. Absence of plateau indicated a possibility of further progress in grain yield using the same procedure, i.e. developing varieties from introduced germplasm. Correlation analysis indicated that grain yield was positively correlated with yield per plant, biomass yield, the number of seeds per plant, seed growth rate, grain yield per day and biomass production rate. The stepwise regression analysis showed that biomass yield was greatly contributed to the variation among the varieties in grain yield. Improvement for high grain yield was potential in haricot bean occurred over the past 26 years, in part, by grain yield improvement *per se*. However, the improvement was also associated with paralleled increase in biomass yield, the number of seeds per plant, seed growth rate, grain yield per day and biomass production rate.

Key words: haricot bean, *Phaseouls vulgaris*, genetic gain, yield potential, germplasm

INTRODUCTION

Haricot bean or common bean (*Phaseolus vulgaris* L.) belongs to order Rosales, family Leguminosae subfamily Papilionideae, tribe Phaseolinae (CIAT, 1986). The center of origin and diversity of haricot bean is considered to be South America and Central America with the Caribbean as an important secondary center of diversity (FAO, 1998). In Ethiopia, it is most likely to be introduced by the Portuguese in the 16th century (Imru, 1985).

Haricot bean is a well-established component of Ethiopian agriculture and it is

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among the five most important food legumes (faba bean, field pea, chickpea, lentils and haricot bean) (Abebe and Kefene, 1989). It has been an export crop for more than 40 years, and grown as a food crop for a much longer period. In many low lands of Ethiopia, haricot bean is considered a main cash crop and protein source for the farmers (Abebe, 1987). At present, different types of haricot beans are grown in the country.

Despite its highly economic importance, the national average yield of dry bean is very low, 840 kg/ha (CSA, 1997). This yield is far less than the attainable yield (2500-3000 kg/ha) under good management condition (Abebe and Kefene, 1989), yet it is also very low compared to the average yield of 2,500 kg/ha in Egypt which is the highest country yield in the world. However, it is a bit higher than the world average yield (600 kg/ha) or some countries like India (300 kg/ha) (Dev and Gupta, 1997). Lack of improved varieties for different agro-ecological zones has been one of the major reasons for the low haricot bean yield in Ethiopia (Abebe and Kefene, 1989). To alleviate this problem, attempts have been made by breeders to identify varieties with stable good yield potential, along with resistance to the major diseases and pests, acceptable seed type and quality but the progress made to improve the genetic potential is not investigated and documented.

Documentation of the contribution of plant breeding to a given crop yield improvement and evaluation of the past gains are useful for identifying areas with potential for planning a future breeding program (Waddington *et al*., 1986). Evans (1993) advocated that an understanding of changes produced by crop breeding on grain yield and its determinants was important to evaluate the efficiency of past improvement work on the advances in genetic yield potential, and to define future selection criteria to facilitate further progress.

Genotype, environment and management interact to determine the yield of a crop. However, no method of estimating long-term improvement progress can completely separate genetic effects *per se* and their interaction effect. Nevertheless, evaluation of popular cultivars from different years in common environments is the most comprehensive and direct method that have been used to estimate progress in yield improvement. Progress made in genetic yield potential and associated changes in morpho-physiological attributes produced by genetic improvement and benefits obtained, thereof, have been documented in different crops in different countries (Perry and D'Antuono, 1989; Austin *et al.*,1989) by comparing old and modern varieties. However, no work has been conducted along this line in haricot bean in Ethiopia. Hence, the present study was undertaken with respect to haricot bean improvement program in Ethiopia with the objectives to estimate the amount of genetic gain made in grain yield potential and to determine changes produced by genetic improvement on associated agronomic traits.

MATERIALS AND METHODS

The experiment was conducted in the experimental field at Awassa Agricultural Research Center (ARC). The center is located at $7^{0}04'$N latitude and 38 $^{0}31'$ E longitude at an altitude of 1700 m.a.s.l. The soil type of the experimental site is of volcanic origin and is classified in the Fluvisol and/or Andosol orders (Beyene, 1982).

Seventeen varieties, representing 10 haricot bean varieties released between 1974 and 1998 and six elite lines being proposed as varieties for release and one local variety (Red Wolayta), were used (Table 1). The experiment was set using randomized complete block design (RCBD) with four replications. Each gross plot size was 9.6 m^2 and consisted of 6 rows of 4 m in length. The four middle-rows, net plot of 6.4 m^2, were considered in recording data. The spacing between rows and between plants within row were 40 cm and 10 cm, respectively. Fertilizer was applied at 100 kg/ha diammonium phosphate (18:46:0) at the time of planting. Pesticides were also applied to control major diseases and insects prevailing in the area. Hand weeding was practiced as frequently as needed. Data were recorded on days to 50% flowering, 95% maturity, plant height (cm), pod length in cm (average length between two ends of a pod based on 5 random pods taken from each 5 random plants), the number of pods per plant (an average number of pods with at least one seed from 5 random plants), the number of seeds per plant (an average number of seeds of 5 random plants), the number of seeds per pod (an average number of seeds divided by the average number of pods), yield per plant (an average grain yield of 5 random plants in g), 100-seed weight (g), biomass yield (kg/ha), grain yield (kg/ha), grain filling period, the harvest index and the following three traits were calculated as indicated below.

Biomass production rate (kg/ha/day) =

$$\frac{\text{above ground biomass yield (kg / ha)}}{\text{days to physiological maturity}}$$

Seed growth rate (kg/ha/day) =

$$\frac{\text{grain yield (kg / ha)}}{\text{days to grain filling period}}$$

Grain yield per day (kg/ha/day) =

$$\frac{\text{grain yield (kg / ha)}}{\text{days to physiological maturity}}$$

To evaluate the difference among the varieties, all measured variables were subjected to analysis of variance following the standard procedure given by Gomez and Gomez (1984). To estimate the annual genetic gain achieved in grain yield and changes produced on associated agronomic traits in haricot bean due to variety improvement program, the mean values of each character for each variety were regressed against the year of release for that variety (0 to 26 years). The year of release was expressed as the number

Table 1 Haricot bean varieties used in the experiment.

Name of variety	Year of release	Major use	Source
Red Wolayta	Pre 1972	Food	Ethiopia
Mexican-142	1974	Export	Kenya
Black Dessie	1974	Food	Ethiopia
Brown Speckled	1974	Food	Ethiopia
Roba-1	1989	Food	CIAT, Colombia
Awash-1	1990	Export	CIAT, Colombia
A-262 (Atndaba)	1996	Food	CIAT, Colombia
Ayenew	1996	Food	Kenya
Gofta	1996	Food	CIAT, Colombia
Cross-14	1998	Food	CIAT, Colombia
Cross-5	1998	Food	CIAT, Colombia
GX-1175-3	Candidate	Food	CIAT, Colombia
TY-3396-7	Candidate	Food	CIAT, Colombia
ICA 15541	Candidate	Food	CIAT, Colombia
MX-2500-19	Candidate	Food	CIAT, Colombia
PAN-173	Candidate	Export	CIAT, Colombia
PAN-182	Candidate	Export	CIAT, Colombia

of years since 1972, the period when coordinated bean improvement program started. Calculation was done as follows.

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

Where, X = the year of variety release
Y = the mean value of each character for each variety
Cov = Covariance
Var = Variance

The relative annual gains achieved over the twenty-six years period in different characters were determined as the ratio of annual genetic gain, which was estimated from regression to the corresponding estimated values of the oldest variety and expressed as a percentage. Simple linear correlation coefficients among all characters were calculated using means of each character. Stepwise regression analyses were carried out on the varietal mean, to determine those variables contributing much to yield variation among the varieties following the standard procedure given by Norusis (1995) using SPSS computer software.

RESULTS AND DISCUSSION

Grain yield potential

The analysis of variance indicated significant differences among the varieties for all traits except harvest index (Table 2) revealing that the varieties tested were highly variable. The mean values for grain yield ranged from 1,947 to 4,519 kg/ha with an average yield of 3,400 kg/ha (data not shown).

Table 3 shows the average grain yield of local variety, varieties released in 1974, 1989, 1990, 1996, 1998, and proposed for release in 1998. The least and highest increases were 390 kg/ha (20%) and 2,077 kg/ha (107%) for the variety released in 1974 and candidate varieties, respectively, over the farmers' local variety, Red

Table 2 Analysis of variance for grain yield and other characters.

Character	Source of variation	
	Variety (16)++	Error (48)
Grain yield	2420517.58**	203759.19
Biomass yield	7090623.31**	670145.21
Harvest index	0.003	0.004
Plant height	412.53**	68.72
Yield per plant	91.58**	0.99
Pod number per plant	114.70**	2.49
Seed number per plant	1750.47**	77.18
Seed number per pod	0.20**	0.28
Hundred seed weight	607.83**	1.17
Pod length	3.59**	0.58
Days to flowering	30.31**	0.97
Days to physiological maturity	51.11**	3.25
Grain filling period	39.58**	3.69
Seed growth rate	757.81**	83.45
Grain yield per day	211.45**	20.70
Biomass production rate	667.95**	69.36

*,** Mean squares of characters were significant at probability level of 0.05 and 0.01, respectively.
++ Numbers in parenthesis represent degrees of freedom

Wolayta. The overall increase in grain yield over the local variety was estimated to be 1,604 kg/ha (82.4%) considering all varieties in the trial, whereas 1,321 kg/ha (67.8%) was obtained excluding varieties proposed for release. Hence, grain yield increased substantially with the release of improved varieties. This was in agreement with the findings of Karamakar and Bhatnagar (1996) which reported a significant increase in grain yield of new soybean cultivars over the older ones.

Varieties derived from introductions yielded an average of 3,714 kg/ha, surpassing the grain yield of the local variety, Red Wolayta and average grain yield of varieties derived from local collection by 91.0 and 68.6%, respectively (Table 4). Varieties derived from local collection yielded 2,379 kg/ha, surpassing local variety (Red Wolayta) only by 22.2%. It was recorded that varieties developed from introduced germplasm contributed a lot to the genetic improvement of the yield potential of haricot bean varieties over the past 26 years.

Plotting mean grain yields of the 17 haricot bean varieties versus the year of release (Figure 1 and 2) showed an upward trend since the mid 1970s (year of the first improved varieties released). The estimated average annual rates of increase in grain yield potential were 69.45 kg/ha/year (Figure 1) and 65.54 kg/ha/year (Figure 2) for all varieties and for the released ones, respectively. Both were significantly different from zero (p£0.01). Results indicated that genotypic change was an important source of increased grain yield. Similarly, Waddington *et al*. (1987) working on durum wheat, Perry and D'Antuono (1989) on Australian spring wheat, Voldeng *et al*. (1997) on soybean and Teklu (1998)on tef reported an increases in yield potential of varieties over years

Table 3 Average grain yield (kg/ha) of haricot bean varieties and increment over the local variety, Red Wolayta.

Variety	Year of release	Average grain yield (kg/ha)	Increment over Red Wolayta	
			kg/ha	%
Red Wolayta	pre-1972	1947	-	-
Mexican-142				
Black Dessie	1974	2337	390	20.0
Brown Speckled				
Roba-1	1989	3704	1757	90.2
Awash-1	1990	3256	1309	67.2
A-262 (Atndaba)				
Gofta	1996	3663	1716	88.1
Ayenew				
Cross-14				
Cross-5	1998	3859	1912	98.12
GX-1175-3				
TY 3396-7				
ICA 15541				
MX-2500-19	Candidate	4024	2077	106.7
PAN-173				
PAN-182				
Released		3268	1321	67.8
Released and candidate		3551	1604	82.4

of variety release.

The average relative annual gain in grain yield of haricot bean varieties since 1972 was 3.24% per year, or about 84.24% for the whole period of 26 years (Table 5). Present results indicated that the plant breeders made substantial progress for over the past 26 years in improving the yields of haricot bean varieties in Ethiopia. Besides, grain yield was plateaued, i.e. it continued to increase with the release of new varieties from the introductions (Table 3, Figure 1 and 2). Further progress in grain yield is expected using the same procedure, i.e. developing varieties from introduced germplasm.

Biomass yield, harvest index and plant height

Varieties developed from introduced germplasm gave a mean biomass yield of 6,834

Table 4 Average grain and biomass yield increment of varieties derived from introduction and local collection over Red Wolayta and varieties derived from introduction over varieties derived from local collection.

Variety	Grain yield (kg/ha)	Grain yield increment over				Biomass yield (kg/ha)	Biomass yield increment over			
		Red Wolayta		Local collection			Red Wolayta		Local collection	
		(kg/ha)	(%)	(kg/ha)	(%)		(kg/ha)	(%)	(kg/ha)	(%)
Red Wolayta	1947					3352				
Local collection derived	2379	432	22.2			4308	956	28.5		
Introduction derived	3714	1772	91.0	1335	68.6	6834	3482	103.9	2526	58.6

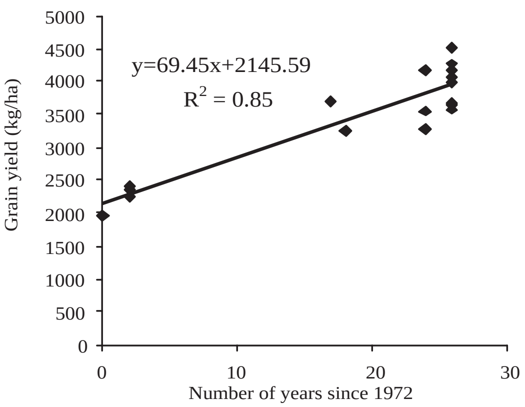

Figure 1 Relationship between mean grain yield of 17 haricot bean varieties and the year of release expressed as the number of years since 1972 (the year when coordinated bean improvement program started).

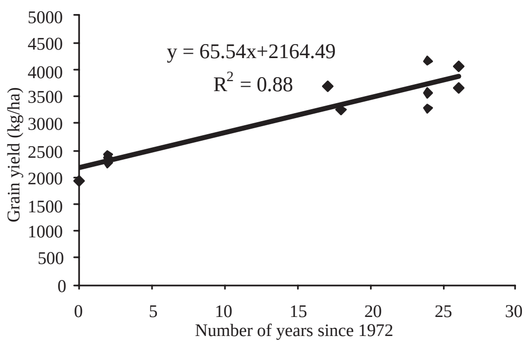

Figure 2 Relationship between mean grain yield of 11 haricot bean varieties (only released ones) and the year of release expressed as the number of years since 1972 (the year when coordinated bean improvement program started).

kg/ha, which showed 2,526 (58.6%) and 3,482 kg/ha (103.9%) increases over the varieties derived from local collection and local variety, Red Wolayta, respectively (Table 4), while the varieties derived from local collections showed only 956 kg/ha (28.5%) increase over the local variety, indicating that much of the increase in biomass was obtained from introduced varieties.

The regression of the mean biomass yields of haricot bean variety on the year of release indicated that there was 122.76 kg/ha/year average annual rate of increase (Table 6). This was significantly larger than zero, revealing that there was a positive trend from the old to the modern varieties in biomass yield. The relative annual biomass yield gain in haricot bean varieties was estimated to be 3.16% per year for the 26 years (Table 5). The present result was in agreement with the findings of Karmakar and Bhatnagar (1996) which reported higher biomass yield in recently developed soybean variety than the older ones. On the other hand, Sinha *et al.* (1981) reported that breeding had failed to raise the biomass of wheat, and the grain yield improvement was solely due to the result of higher harvest index.

The mean harvest index of varieties was high, 0.57 (data not shown), which was probably associated with greater shedding of leaves aggravated by high rainfall occurring around maturity before harvesting. Likewise, higher harvest index value of 0.59 for chickpeas (Saxena *et al.*, 1983) was reported as the result of greater loss of leaves before measurements. Unlike the present result, mean harvest index as low as 0.32 for wheat was reported (Perry and D'Antuono, 1989).

Lack of trend of increasing in harvest index (Table 6) in the present study was in agreement with Teklu (1998) who found the unchanged harvest index in tef for the period of genetic improvement. As opposed to these, significant change in the harvest index was observed with the release of modern varieties of wheat (Perry and D'Antuono, 1989; Tarekegne,

Table 5 The annual relative genetic gain and correlation of characters with grain yield of haricot bean varieties represented in the yield potential trial.

Character	Relative genetic gain(%year^{-1})	Correlation coefficient (r)
Grain yield	3.24	
Biomass yield	3.16	0.965**
Harvest index	0.05	0.316
Plant height	-0.33	-0.146
Yield per plant	3.22	0.891**
Pod number per plant	0.83	0.465
Seed number per plant	1.90	0.503*
Seed number per pod	0.05	0.106
Hundred seed weight	1.41	0.261
Pod length	0.31	0.326
Days to flowering	-0.06	-0.019
Days to physiological maturity	0.07	0.265
Grain filling period	0.21	0.318
Seed growth rate	2.75	0.966**
Grain yield per day	3.07	0.987**
Biomass production rate	3.01	0.913**

* ** Values were significantly different at the probability level of 0.05 and 0.01, respectively.

1994).

Despite an increase in biomass, there was a non-consistent gradual reduction in plant height from the older to the newer varieties. As it was estimated from regression of variety means against year of release, the annual rate of gain, -0.215 cm/ha/year, was not different from zero (Table 6). This implied that yield potential improvement program did not markedly affect this trait. Similarly, a non-significant reduction, maintained plant height, had generally been reported in tests of soybean cultivars (Voldeng *et al*., 1997). In contrast, Karmakar and Bhatnagar (1996) found a conspicuous reduction in plant height despite an increase in biomass. In peanut significant and shortened main stem and lessened biomass production was also observed (Wells *et al*., 1991).

Grain yield per plant and yield components

The average grain yield per plant of all varieties was estimated to be 20.37 g/plant and ranged between 11.3 and 26.10 g/plant (data not shown). The yield potential improvement program substantially improved grain yield per plant with annual rate of gain of 0.408 g/plant/year (Table 6) and a very high (3.22%) annual relative change was achieved (Table 5).

Though it seemed that there was an increasing tendency in the number of pods per plant with an average annual rate of gain of 0.119 pods/plant/year (Table 6), the test proved that no significant change was achieved by the improvement program since the start of coordinated bean improvement program in 1972. Likewise, Wells *et al*. (1991) observed a non-significant change in the number of pods per plant of peanut varieties as a result of fifty years breeding. Nevertheless, earlier research by Boerma (1979) revealed a 3.9-pods/m/year increase though it was only in maturity group VIII soybean cultivars.

The average annual rate of gain of seed

Table 6 Estimation of mean values and regression coefficient (b) of various morpho-physiological traits from linear regression of the mean value of each character for each variety against the year of release for that variety.

Character	Mean (1972)	Regression coefficient (b)(1972-1998)
Grain yield	1947.00	69.451
Biomass yield	3881.40	122.758**
Harvest index	0.55	0.0003
Plant height	63.75	-0.215
Yield per plant	12.97	0.408**
Pod number per plant	14.33	0.119
Seed number per plant	51.56	0.978*
Seed number per pod	3.68	0.002
Hundred seed weight	24.45	0.345
Pod length	8.72	0.027
Days to flowering	49.28	-0.032
Days to physiological maturity	99.56	0.073
Grain filling period	50.28	0.105
Seed growth rate	43.50	1.198**
Grain yield per day	21.64	0.665**
Biomass production rate	39.13	1.179**

*,** Values were significantly different from zero at the probability level of 0.05 and 0.01, respectively.

number per plant over 26 years was 0.978 seeds/plant/year (Table 6). This gain was significantly ($p \leq 0.05$) different from zero, showing that this yield component was altered parallel to the release of improved varieties, and relative genetic gain was estimated to be 1.9% per year (Table 5). Likewise, Waddington *et al*. (1987) working on durum wheat, Perry and D'Antuono (1989) on Australian spring wheat and Tarekegne (1994) on bread wheat found significant increase in the number of grains per m^2 over the period of genetic improvement. In contrast, Duvick (1984), reported that the newer maize hybrids tended to have fewer seeds per plant.

An insignificant relative annual gain of 0.05% per year or only 1.30% for the whole period of yield improvement program (26 years) was obtained in the number of seeds per pod (Table 5). Similar to the finding of Boerma (1979) on soybean, the rate of annual gain, 0.002 seeds/pod/year, did not show a significant difference from zero (Table 6). Hence, the change did not appear as a consistent trend.

The estimated annual rate of gain in 100-seed weight due to genetic improvement was 0.345 g/100-seeds/year and it showed non-significant trend with the year of release (Table 6), as reported earlier by Voldeng *et al*. (1997) for short season soybean in Canada. One hundred seed weight was also not significantly affected with the release of improved varieties. However, a significant annual increase in a hundred seed weight occurred in USA in all the maturity groups of soybean released during the period 1902 to 1977 (Specht and Williams, 1984).

Although most recently released and candidate varieties possessed longer pod length, regression of mean pod length of variety over the year of variety release showed non-significant trend (Table 6). The average relative annual gain of pod length was also very low of 0.31% per year (Table 5), indicating that pod length remained unchanged over the past 26 years of yield potential improvement program.

Phenological traits

Like plant height, the regression analysis indicated a negative regression coefficient in days to flowering which was 0.032. However, this value was not significantly different from zero (Table 6). This insignificant reduction occurred due to early flowering character of some recently released varieties such as Ayenew and Cross-14 (data not shown). Hence, the change in days to flowering was not associated with the time of release of the varieties. This was in agreement with the report of Karmakar and Bhatagar (1996) on soybean varieties released in India from 1969 to 1993.

Since 1972, the relative annual change of physiological maturity was found to be very low, 0.07%, per year or only 1.82% over 26 years period (Table 5). The estimated annual rate of changes was in opposite direction with that of days to flowering; however, it was non-significant ($b=0.073$), as it was observed for days to flowering (Table 6). In similar studies on soybean, Karmakar and Bhatnagar (1996) and Voldeng *et al*. (1997) found that the days taken for maturity remained unchanged.

A very low annual relative change (0.21 % per year) was achieved for grain filling period as well (Table 5). This made clear that the change in grain filling period was not paralleled with the release of improved variety regardless of some recently released varieties possessed longer period. Similar results were reported by Salado-Navarro *et al*. (1993) as opposed to Karmakar and Bhatnagar (1996) who found an 11% increase of grain filling duration in soybean.

Seed growth rate, grain yield per day and biomass production rate

Both seed growth rate and grain yield per day increased significantly ($p \leq 0.01$) with the annual rates of genetic gain of 1.198 and 0.665 kg/ha/day/year, respectively (Table 6). Moreover, the relative annual gain of 2.75% per year for seed growth and 3.07% per year for grain yield per day (Table 5) were very high, indicating that these characters were effectively and significantly improved due to the 26 years period of grain yield potential improvement. This was in agreement with the investigation of Waddington *et al*. (1987) and Tarekegne (1994) on wheat. However, Teklu (1998) reported that the most modern and older tef cultivars had similar rate of total grain filling rate.

In the previous study made on wheat, Waddington *et al.* (1987) reported a clear trend to greater rate of above ground biomass production with the year of release which was similar to the result of this experiment, that an increased trend towards the recent improved varieties was achieved with an annual rate of 1.179 kg/ha/day/ year (Table 6) and a relative gain of 3.01%/year (Table 5) or 78.26% over 26 years of grain yield potential improvement program. From this, it cald be concluded that substantial improvement was apparent in the rate of biomass production due to grain yield potential improvement program. In contrast, reduction in biomass production rate in modern wheat varieties was indicated by Tarekegne (1994).

Basis of yield gain- morpho-physiological characters associated with yield potential improvement

Grain yield was related positively (r=0.965, p£ 0.01) with biomass yield, but showed no association with harvest index (Table 5). Similarly, Laing *et al*. (1984) on haricot bean, Salado-Navaro *et al*. (1993) on soybean and Teklu (1998) on tef found positive association between grain yield and biomass yield but no association between grain yield and harvest index. In contrast, no relation between grain yield and biomass yield and positive association between grain yield and harvest index were reported on bread wheat (Tarekegne, 1994). Other authors also reported grain yield to have positive association with both biomass yield and harvest index (Riggs *et al*., 1981; Waddington *et al*., 1987; Perry and D' Antuono, 1989). Hence, the result reported herein indicated that grain yield potential improvement resulted from biomass production rather than the harvest index.

No correlation between grain yield and plant height (Table 5) observed in the present study was in contrary with the finding of Riggs *et al*. (1981) which reported positive association in wheat and negative association in spring barley, respectively, between grain yield and harvest index. The lack of association between grain yield and days to flowering, days to physiological maturity and grain filling period (Table 5) observed herein supported the findings of Teklu (1998) which found association for grain yield with the above three traits in tef. Similarly, Salado-Navaro *et al.* (1993) found no correlation but positive association for grain yield with days to flowering and grain filling period in soybean. On the other hand, Laing *et al.* (1984) and Salado-Navaro *et al.* (1993) reported positive association for grain yield with days to physiological maturity as opposed to significantly negative association obtained between the same in wheat (Waddington *et al*., 1987).

As shown in Table 5 , positive correlation coefficients were obtained for grain yield with yield per plant (r=0.891, p£ 0.01) and number of seeds per plant (r=0.503, p£0.05); however, the number of pods per plant, the number of seeds per pod, a hundred seed weight and pod length did not show association with grain yield. Several authors also observed no association between grain yield and hundred seed weight (Riggs *et al.*, 1981; Waddington *et al.*, 1987; White and Izquierdo, 1991; Tarekegne, 1994; Teklu, 1998). In contrast, the positive correlation were recorded for grain yield with the number of seeds per pod and mean seed weight in soybean (Karmakar and Bhatnagar, 1996), with the number of grains per ear in wheat

(Waddington *et al.*, 1987 and Perry and D' Antuono, 1989).

Seed growth rate, grain yield per day and biomass production rate were positively associated with grain yield (Table 5). This was in agreement with the work of Scully *et al*. (1991) which obtained similar result for all three above-mentioned traits. Moreover, correlation between grain yield with grain yield per day (White and Izquierdo, 1991), with grain yield per day and biomass production rate (Teklu, 1998) and with biomass production rate (Waddington *et al.,* 1987) were reported.

A stepwise regression analysis equation expressing the relation of grain yield to the agronomic characters was reduced (grain yield =0.965+0.564**BMY, R^2=0.827) revealing that BMY (biomass yield) was the most important character, which greatly contributed to 82.7% of the variation in grain yield among the varieties. Similarly, Tollenar (1989) reported that 85% of the genetic gain in grain yield of maize was attributed by the increased total dry matter accumulation.

CONCLUSION

During the period 1972 to 1998, substantial progress was made in improving the grain yield potential of haricot bean. Moreover, changes occurred on the associated morpho-physiological characters parallel to varietal release. The present study revealed that the genetic yield potential improvement of haricot bean over the last 26 years was associated with paralleled increases in biomass yield, the seed number per plant, seed and grain yield per plant and biomass production rate as these traits were strongly correlated with grain yield and the year of varietal release. The use of selection criteria based on a physiological appreciation of yield determination in haricot bean, in addition to selection for grain yield *per se*, was responsible for the improvement of grain yield potential.

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