

African Crop Science Journal by African Crop Science Society is licensed under a Creative Commons Attribution 3.0 Uganda License. Based on a work at [www.ajol.info/](http://www.ajol.info/) and [www.bioline.org.br/cs](http://www.bioline.org.br/cs)  
DOI: <https://dx.doi.org/10.4314/acsj.v30i4.9>



## GENETIC PROGRESS ACHIEVED IN BEAN BREEDING IN UGANDA

A. MUKAYIRANGA<sup>1,2</sup>, P. RUBAIHAYO<sup>1</sup>, P.T. GIBSON<sup>1</sup>, R. EDEMA<sup>1</sup>, S.T. NKALUBO<sup>2</sup>,  
Z.A. CHITEKA<sup>1</sup> and A. RUTAYISIRE<sup>1,2</sup>

<sup>1</sup>College of Agricultural and Environmental Sciences, Department of Agricultural Production,  
P. O. Box 7062, Makerere University, Kampala, Uganda

<sup>2</sup>National Crops Resources Research Institute, P. O. Box 7084, Kampala, Uganda

**Corresponding author:** [prubaihayo@gmail.com](mailto:prubaihayo@gmail.com)

(Received 4 June 2022; accepted 29 September 2022)

### ABSTRACT

Several cultivars of common bean (*Phaseolus vulgaris* L.) have been released in Uganda over a period of five decades, but the genetic gain to selection in respect of yield and agronomic characteristics has not been determined. This study was conducted to estimate the gain in selection over the 1960 - 2016 period, of common bean breeding in Uganda. Twenty nine bush and eleven climbing type cultivars were evaluated for yield and yield components, in three locations, during 2017B and 2018A cropping seasons. The study was carried out at the National Crop Resources Research Institute (NaCCRI), Nakabango Research Institute in central and Kwachwekano Zonal Agriculture Research Institute in southwestern Uganda. The design used was a randomised complete blocks with three replicates for the climbing types; and a 3x10 Alpha lattice design with three replicates for bush types. Significant differences ( $P<0.001$ ) were recorded among cultivars for most traits in both bush and climbers, except seed number per pod (NSP). The range of genetic gain in grain yield was between 1,505 to 2,418 kg ha<sup>-1</sup> for bush type cultivars, and 1,641 to 2,687 kg ha<sup>-1</sup> for the climbing types. Yield has increased by 16.3 and 26.3 kg ha<sup>-1</sup> per year for bush and climbers, respectively; with a relative gain of 1.27%/year for bush types and 1.54%/year for the climbing types. Biomass yield and harvest index explained most of the variation in grain yield and number of pods per plant in climbing types. Among climbing types, biomass yield was significantly and positively correlated with grain yield per plant and grain yield per ha ( $P<0.05$ , and  $r=0.87$ ) and with grain yield per ha ( $P<0.01$   $r=0.98$ ) for bush types, biomass yield was significantly and positively correlated with grain yield per plant ( $P<0.05$ , and  $r=0.59$ ) and with grain yield per ha ( $P<0.01$   $r=0.80$ ) and harvest index ( $P<0.5$   $r=0.80$ ).

**Key Words:** Annual rate of gain, biomass, grain yield, harvest index

### RÉSUMÉ

Plusieurs cultivars de haricot commun (*Phaseolus vulgaris* L.) ont été diffusés en Ouganda sur une période de cinq décennies, mais le gain génétique de la sélection en termes de rendement et de caractéristiques agronomiques n'a pas été déterminé. Cette étude a été menée pour estimer le gain en

sélection sur la période 1960 - 2016, de la sélection du haricot commun en Ouganda. Vingt-neuf cultivars buissonnants et onze cultivars grimpants ont été évalués pour les composantes de rendement et de rendement, dans trois endroits, au cours des saisons de culture 2017B et 2018A. L'étude a été menée à l'Institut national de recherche sur les ressources agricoles (NaCCRI), à l'Institut de recherche de Nakabango dans le centre de l'Ouganda et à l'Institut de recherche agricole de Kwachwekano dans le Sud-ouest de l'Ouganda. La conception utilisée était un bloc complet randomisé avec trois répétitions pour les cultivars grimpants ; et une conception de réseau Alpha 3x10 avec trois répétitions pour les cultivars buissonnants. Des différences significatives ( $P < 0,001$ ) ont été enregistrées entre les cultivars pour la plupart des caractères des cultivars buissonnants et des cultivars grimpants, à l'exception du nombre de graines par gousse (NSP). La gamme de gain génétique dans le rendement en grain allait de 1 505 à 2 418 kg ha<sup>-1</sup> pour les cultivars buissonnants et de 1 641 à 2 687 kg ha<sup>-1</sup> pour les cultivars grimpants. Le rendement a augmenté de 16,3 et 26,3 kg ha<sup>-1</sup> par an pour les cultivars buissonnants et les cultivars grimpants, respectivement ; avec un gain relatif de 1,27%/an pour les cultivars buissonnants et de 1,54%/an pour les cultivars grimpants. Le rendement de la biomasse et l'indice de récolte ont expliqué la majeure partie de la variation du rendement en grains et du nombre de gousses par plante dans les cultivars grimpants. Parmi les cultivars grimpants, le rendement en biomasse était significativement et positivement corrélé avec le rendement en grain par plante et le rendement en grain par ha ( $P < 0,05$  et  $r = 0,87$ ) et avec le rendement en grain par ha ( $P < 0,01$   $r = 0,98$ ) pour les cultivars buissonnants, la biomasse le rendement était significativement et positivement corrélé avec le rendement en grains par plante ( $P < 0,05$  et  $r = 0,59$ ) et avec le rendement en grains par ha ( $P < 0,01$   $r = 0,80$ ) et l'indice de récolte ( $P < 0,5$   $r = 0,80$ ).

*Mots Clés* : taux de gain annuel, biomasse, rendement en grains, indice de récolte

## INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a popularly grown grain legume and accounts for 32% of the human calorie intake in parts of Eastern Africa and Latin America (Broughton *et al.*, 2003). The crop plays important roles in food security in sub-Saharan Africa; being a source of income, protein, complex carbohydrates, vitamin B components, (thiamin, folic acid and niacin) and micro-nutrient (iron and zinc) (CIAT, 2014). Additionally, the crop is used as fodder, contributes to the soil fertility and provides a market opportunity with high demand in urban and rural areas.

The *per capita* consumption of beans in Uganda is about 26 kg per year and ranks fifth in export volume as a food crop after banana, cassava, sweet potatoes and maize (FAOSAT, 2015). The estimated total production of beans in Uganda is 929,274 metric tonnes per year

(UBOS, 2015). The national bean-breeding programme has contributed to the production and productivity of beans through the release and promotion of their adoption by farmers since the 1960s (CIAT, 2008).

Despite the considerable number of bean cultivars released and adopted by the farming communities since the 1960s, there has been no systematic efforts to quantify the gain in yield and its general achievements through breeding. This information is important, firstly to justify continued funding of the bean breeding programmes, secondly enabling the programmes to quantify the advances in genetic potential achieved through continued breeding and selection in Uganda; and thirdly identifying the traits responsible to the achieved gain to facilitate further progress. The objective of this study, therefore, was to estimate the gain through selection over the 1960 - 2016 period of common bean breeding in Uganda.

**MATERIALS AND METHODS**

The study used forty bean cultivars released over a period of 56 years (1960-2016), along with local cultivars produced by some farmers (Table 1). The bush and climbing type cultivars

were planted in two different experiments at three sites that represent the major bean growing areas of Uganda. These were, the National Crop Resources Research Institute (NaCCRI) (0°32'N) and (32°53'E), Kwachwekano Zonal Agriculture Research

TABLE 1. Identities of the twenty-nine bush type and eleven climbing cultivars released between 1960 for bush and 1980 for climbers, their pedigrees, and purpose of release

No.	Bean types	Varieties	Pedigree	Breeding purpose	Year of release
1	Bush	MUTIKE 4		Yield	1961
2	Bush	BANJA 2		Yield	1968
3	Bush	K20		Yield and ANTHR resistance	1970
4	Bush	K131	IVTB31607 XRAB71	Yield and BCMV resistance	1994
5	Bush	K132	CALIMAXARGENTI	Yield	1995
6	Bush	NABE2	IVT831629XBAT1554	Yield and BCMV resistance	1995
7	Bush	NABE 3	IVT831607 XRAB71	Yield and BCMV	1995
8	Bush	NABE4	SUG58 XCAL103	Yield, CBBALS resistance	1999
9	Bush	NABE5	AFR 88XAFR199	Yield, CBB, ALS resistance	1999
10	Bush	NABE6	Multlines UBR(25)MR	Yield and ANTHR resistance	1999
11	climber	NABE7C	G685 / Rwanda	Yield	1999
12	climber	NABE8C	59/1-2/ Rwanda	Yield, early maturing& taste	1999
13	climber	NABE 9C	Rwanda	Yield and market class	1999
14	climber	NABE10C	Rwanda	Yield	1999
15	climber	NABE12C	GOLDO X A487	Yield, ALS, CBB resistance	2002
16	Bush	NABE13		Yield and root rot resistance	2006
17	Bush	NABE14		Yield	2006
18	Bush	NABE15	Kanyebwa X P120762	Yield and ANTHR resistance	2010
19	Bush	NABE 16	Kanyebwa X G2333	Yield and ANTHR resistance	2010
20	Bush	NABE17	Kanyebwa X G2333	Yield and ANTHR resistance	2012
21	Bush	NABE 18	K132 XNAT067	Yield, ANTHR resistance.	2012
22	Bush	NABE 19	Kanyebwa x K132	Yield, ANTHR resistance	2012
23	Bush	NABE20	K132 X G2333	Yield and BCMV resistance	2012
24	Bush	NABE21	Kanyebwa X NAT003	Yield, ANTHR resistance	2012
25	Bush	NABE 22	K132 X NAT 067	Yield and BCMV resistance	2012
26	Bush	NABE 23	Kanyebwa X K132	Yield, high palatability, market class traits	2012
27	climber	NABE 26 C	MAC31 XMLB49-89A	Yield and Pythium resistance	2012
28	climber	NABE 28C	MAC31XMLB49-89A	Yield and early maturity	2012
29	climber	NABE 29C	MAC31 X MLB 49-89A	Yield and early maturity	2012
30	Bush	NAROBAN1	Rwanda	High( iron and zinc) content	2016
31	Bush	NAROBAN2	Rwanda	High ( iron and zinc) content	2016
32	Bush	NAROBAN3	CIAT	High (iron and zinc) content	2016
33	climber	NAROBAN 4C	CIAT	High (iron, zinc) content	2016
34	climber	NAROBAN 5C	G 858	High (iron, zinc) content	2016
35	climber	SUGAR LOCAL	Landrace	Local cultivar	1980
36	Bush	MASSINDI Y.L	Landrace	Local cultivar	1950
37	Bush	MASSINDI Y.S	Landrace	Local cultivar	1950
38	Bush	KAHURA	Landrace	Local cultivar	1950
39	Bush	KANYEBWA	Landrace	Local cultivar	
40	Bush	DOOR500	Candidate line	To be released	

Institute (KAZARDI), 1°15'07.04''S); and Nakabango Research Institute (29°56.06''E) during the second rains (2017B) and first rainy season of 2018(2 018A). The design used for the climbing types was a randomised complete block design (RCBD), with three replicates; and a 3x10 alpha lattice design with three replicates for bush types. Plots consisted of seven rows, spaced at 50 cm and 10 cm within row for bush, and 20 cm within row for climbers. Fertiliser application followed recommendations based on soil analysis results to ensure ideal conditions for development and production.

**Data collection and statistical analysis.** Data were collected on grain yield per plant, grain per ha, above ground biomass at maturity, harvest index, number of pods per plant, number of seeds per pod, and hundred seed weight and plant height were recorded at maturity stage.

The analysis of variance was computed using GenStat 18<sup>th</sup> edition, for both within site and across sites, following the procedure of Gomez and Gomez (1984). The genetic progress on grain yields for bush types for 56 years and climbers for 36 years was determined as the slope of the regression line determined according to Evans and Fisher (1999).

The relative annual gain achieved in 56 years for different characters, was estimated as a ratio of genetic gain to the corresponding mean value of the local cultivar (Evans and Fisher, 1999). The increment in yield and the relative rate of gain over years were the statistics used. The year of release (YOR) was used as the number since 1960 for bush types or 1980 for the climbing types. Pearson correlation coefficients among all pairs of characters were estimated

## RESULTS AND DISCUSSION

**Genotype- x -environment interactions.** Analysis of variance of the various traits in

bush and climbing types are presented in Table 2.

**Bush types.** The results revealed significant genotype by location x season (GLS) interaction ( $P < 0.001$ ) for biomass yield, grain yield, number of pods per plant and 100 seed weight and ( $P < 0.05$ ) for harvest index and plant height (Table 2). There were no significant interactions for number of seed per pod (NSP), 50% flowering and 95% physiological maturity. There was a significant genotype x site interaction ( $P < 0.001$ ) for all variables, except days to 50% flowering, 95% physiological maturity and number of seed per pod. There was a significant genotype x location interaction ( $P < 0.05$ ) for 95% physiological maturity and ( $P < 0.001$ ) for all other variables, except for number of seed per pod and hundred seed weight where there was no significant interaction.

These results indicate that the relative performance of the genotypes with respect to number of seed per pod did not change with the environments, i.e. location and season. Results also showed that environment had little effect on the relative performance of genotypes with respect to maturity characters, i.e. days to 50% flowering and days to 50% physiological maturity. which was similar to what the literature was reporting.

Final grain yield and other yield components were highly influenced by the environment (Table 2). This difference in performance of cultivars could have been caused by the past breeding efforts that focussed on development of cultivars adapted to specific environments leading to the high G x E interactions observed, given the unique genetic constitution of the cultivars and the inconsistency in ranking in the performance of the genotypes in different environments could explain the observed results ( Barili *et al.*, 2016).

**Climbing types.** There was significant genotype x season x location interaction ( $P < 0.001$ ) for hundred seed weight ( $P < 0.0001$ )

TABLE 2. Analysis of variance of bush and climbing bean types used to trace genetic gain in Uganda over the period of 1960-2016

Types	Traits	Source of variation						CV (%)	
		G (28)	GL (56)	GS (28)	GLS (56)	ERR (250)	GM		
Bush	50%F	60.88***	26.16***	2.31NS	2.25 NS	4.44	57.08	5.6	
	95MAT	97.71***	36.55*	1.4NS	1.51NS	26.59	96.91	4.2	
	BY ha <sup>-1</sup>	604778.14***	230308.64***	202522.35***	135960.53***	12736.75	4,291.51	7.4	
	GY ha <sup>-1</sup>	315881.92***	63176.35***	91085.96***	61372.5***	24019.26	1,857.95	12.4	
	GY P <sup>-1</sup>	20.36***	6.85***	202522.36***	4.97***	2.14	15.99	11.5	
	HI	77.13***	28.22***	37.94***	21.85*	13.97	49.21	7.3	
	NPP	1.99***	2.11***	3.56***	1.72***	0.8	11.93	4.8	
	NSP	1.08***	0.246NS	0.22NS	0.26NS	0.46	4.88	8.6	
	PH	36.11***	10.81***	19.38***	7.28*	4.97	28.74	8.5	
	SW	239.08***	1.04NS	81.095***	8.18***	21.062	34.51	18.3	
	Climbers		(10)	(20)	(10)	(20)	(120)		
		50%F	40.018***	14.919***	15.487***	4.683***	1.05	56.5	1.8
MAT		82.98***	38.39***	2.31NS	1.04NS	0.71	99.29	0.8	
BY ha <sup>-1</sup>		2385905.5***	253823.6***	2797785.7***	315840.6***	32,168.19	4,988.50	3.6	
PH		1011.11***	393.65***	878.04***	395.85***	57.74	179.34	4.2	
NPP		50.28***	10.13945***	13.59***	15.4***	1.26	26.17	4.3	
NSP		1.453***	0.16NS	0.354NS	0.20NS	0.29	5.87	9.1	
GY ha <sup>-1</sup>		601609.3***	50003.3***	146680.5***	47594.85***	12,328.44	2,337.64	4.7	
GYP		199.66***	17.3795NS	94.409***	39.0325***	14.98	71.48	5.4	
SW		140.03***	28.65***	59.08***	23.29**	10.85	46.56	7.1	
HI		22.8838***	15.1456***	46.01***	26.29***	6.23	43.96	5.7	

Genetic progress achieved in bean breeding

50% F = days to fifty percent flowering, BY ha<sup>-1</sup> = biomass yield per hectare, GY ha<sup>-1</sup> = grain yield per hectare, GYP = grain yield per plant, HI = harvest index, NPP = number of pods per plant, NSP = number of seeds per plant, SW = hundred seed weight, SOV = source of variation, G = genotypes, GL = genotype by location interaction, GS = genotype by season interaction, GLS = genotype by location by season interaction, ERR = pooled error, GM = grand mean, CV% = coefficient of variation. \*, \*\*, and \*\*\* denotes significance at P=0.05, 0.01 and 0.001, respectively, number in parenthesis represent the degree of freedom

and other variables, except for days to 95 % physiological maturity and number of seeds per pod was observed (Table 2). This underscores the importance of season and location to the performance of the traits. There was also a significant genotype x season interaction for all variables, except days to 95% physiological maturity and number of seed per plant, where there was no significant interaction. Additionally, there was a significant genotype x location interaction ( $P < 0.05$ ) for all variables, except for days to 95 percent physiological maturity and number of seed per plant. There was a significant genotype x location interaction ( $P > 0.05$ ) for all variables, except number of seed per plant and grain yield per plant where there was no significant interaction.

The results indicate that the environment had no significant influence on the number of seeds per pod and days to 95 percent physiological maturity; such that the relative genotype performance with respect to these traits was consistent across environments. Similar results were obtained for number of days to 95% physiological maturity for the bush types. Number of days to 50 percent flowering was, however, influenced by the environment for the climbing types. The environment influenced number of days to 50 percent flowering much less in the climbing than bush types, suggesting that the genes controlling maturity in the two groups are different and, therefore, the two types would need different methods to improve these traits.

**Genotype performance.** There were significant ( $P < 0.001$ ) differences among genotypes for all characters measured, within the bush and the climbing types (Table 2). This was consistent with the fact that selection and release of cultivars depended on superiority for the different characters over the previous cultivars, as the years progressed. For the bush types, the mean biomass yield was 4,291.51 kg ha<sup>-1</sup> and the mean grain yield was 1,857.95 kg ha<sup>-1</sup>; while mean days to 95 percent physiological maturity was 96.91 days. The

mean days to 50 percent flowering was 57.08, while the mean biomass yield for climbers was 4,988.50 kg ha<sup>-1</sup>. Also, the mean grain yield was 2,337.64 kg ha<sup>-1</sup>, mean days to 95 percent physiological maturity was 99.29 days; while the mean days to 50 percent flowering was 56.5. The harvest index for the bush types was 49.21 compared to 43.96 for the climbing types suggesting that different genes are at play. These differences clearly indicated that there was still latitude to continue improving the performance of the cultivars by deploying various breeding techniques. The increment in yield percent of cultivars released above the local cultivars in the bush types, are presented in Table 3

**Genetic gain in grain yield.** The mean grain yields achieved with the release of each cultivar are presented in Table 3. Among the bush types, yield gain ranged from 1481 kg ha<sup>-1</sup> for the local cultivars to 2374 kg ha<sup>-1</sup>, the mean for NAROBAN 1 and NAROBAN 2 released in 2016. Generally, the improved cultivars showed yield superiority of 894.33 kg ha<sup>-1</sup> or 60.4 % over the local cultivars (Table 3). The substantial increase in yield over decades resulted from genetic improvements in the cultivars over time. Evaluation of the cultivars under similar agronomic conditions eliminated the possible effects of environment.

The local cultivars had yield of 234.61 kg ha<sup>-1</sup> or (15.84%); which was significantly higher than cultivar Mutike that was released in 1961. Mutike was mainly developed for resistance to disease and the breeding effort led to the improved yield (Leakey *et al.*, 1970). Over the years, the cultivar lost its genetic resistance to bean common mosaic virus disease (BCMV) (Mukayiranga, 2019), which was probably the cause of the reduced yield of this cultivar, relative to the mean of the local cultivars.

The results of the mean yields of cultivars released after 1960, especially those released from 1995 which were developed from parents of diverse gene pools, pyramiding of disease resistance genes achieved high yields and

TABLE 3. Mean grain yield of bush cultivars released in the same year

Varieties	Year of release	Mean grain yield (kg ha <sup>-1</sup> )	Increment over older cultivars (kg ha <sup>-1</sup> )	Increment (%)
KAHURA KANYEBWA MASINDI YL MASINDI YS	1950	1480.51	-	-
MUTIKE	1961	1245.9	-234.61	-15.84
BANJA 2	1968	1688	207.9	14.04
K20	1970	1716.14	235.63	15.9
K131 K132	1994	2041.22	560.71	37.8
NABE2	1995	2065.12	584.61	46.92
NABE3 NABE4 NABE5	1999	2154.54	674.03	45.52
NABE 13 NABE14	2006	2255	775.18	52.35
NABE15 NABE16 NABE 17 NABE 18 NABE19	2010	2217.85	737.34	49.8
NABE 20 NABE 21 NABE 22 NABE 23	2012	2271.59	791.08	53.43
NAROBAN 1 NAROBAN 2 NAROBAN 3	2016	2374.84	894.33	60.4

The value represents the mean of all the cultivars released during the given year

disease resistance from the breeding efforts. The results of grain yield in climbing beans over the years of release are presented in Table 4.

The yield ranged from 1641 kg ha<sup>-1</sup> for Sugar Local released in 1980 to 2687.2 kg ha<sup>-1</sup> for NAROBAN 4C and NAROBAN 5C released in 2016. These results indicated that yield progressively increased among climbing type over time. The highest yielders were NAROBAN4C, NAROBAN5C with a mean of 2687.83 or 63.9% higher than the local check. There were no improved cultivars released from 1980 until 1999 due to a curtailed programme on this crop. Cultivars NABE 7C, NABE 8C, NABE 9C, and NABE 10C were released in 1999 from the residual programme and yet these four were 39.52% higher than the 1980 released cultivars indicating the effectiveness of the selection. The most recent ones released in 2016, yielded 24.38% more than the cultivars released in 1999 (Table 4).

**Mean annual relative genetic gain.** The relative genetic progress observed was 1.27 and 1.54% per year for bush and climbing bean, respectively (Fig. 1); while for biomass the gain was 0.32 and 1.09% in bush and climbers, respectively. This indicates an upward trend in each trait. Grain yield per plant, in the case of the bush type was 0.32%, indicating the importance of this trait in grain yield improvement. The results showed a much larger gain in climbers (0.89%), indicating that in the case of this bean type, this trait is very important in influencing total grain yield per hectare, especially since this crop had undergone selection for a short time and, therefore, still had considerable genetic diversity.

Among the bush cultivars, yield gradually increased (Fig. 1A) from the time the first improved cultivar was released, with the R<sup>2</sup> for the model being 0.815. This indicates that change of cultivar accounted for 81.5% in yield

TABLE 4. Mean grain yield of climbing cultivars released per year over the period of 1960-2016

Varieties	Year of Release	<sup>1</sup> Mean grain Yield kg ha <sup>-1</sup>	Increment over mean of 1980 cultivars	% Increment over mean of 1980 cultivar
SUGAR LOCAL	1980	1641.09	-	-
NABE 7C	1999	2289.66	648.58	39.52
NABE 8C	1999			
NABE 9C	1999			
NABE 10C	1999			
NABE 12C	2002	2388.45	737.46	45.5
NABE 26C	2012	2383.39	742.3	45.2
NABE 28C	2012			
NABE 29C	2012			
NAROBAN 4C	2016	2687.83	1046.74	63.9
NAROBAN 5C	2016			

<sup>1</sup>The value represents the mean of all the cultivars released during the given year



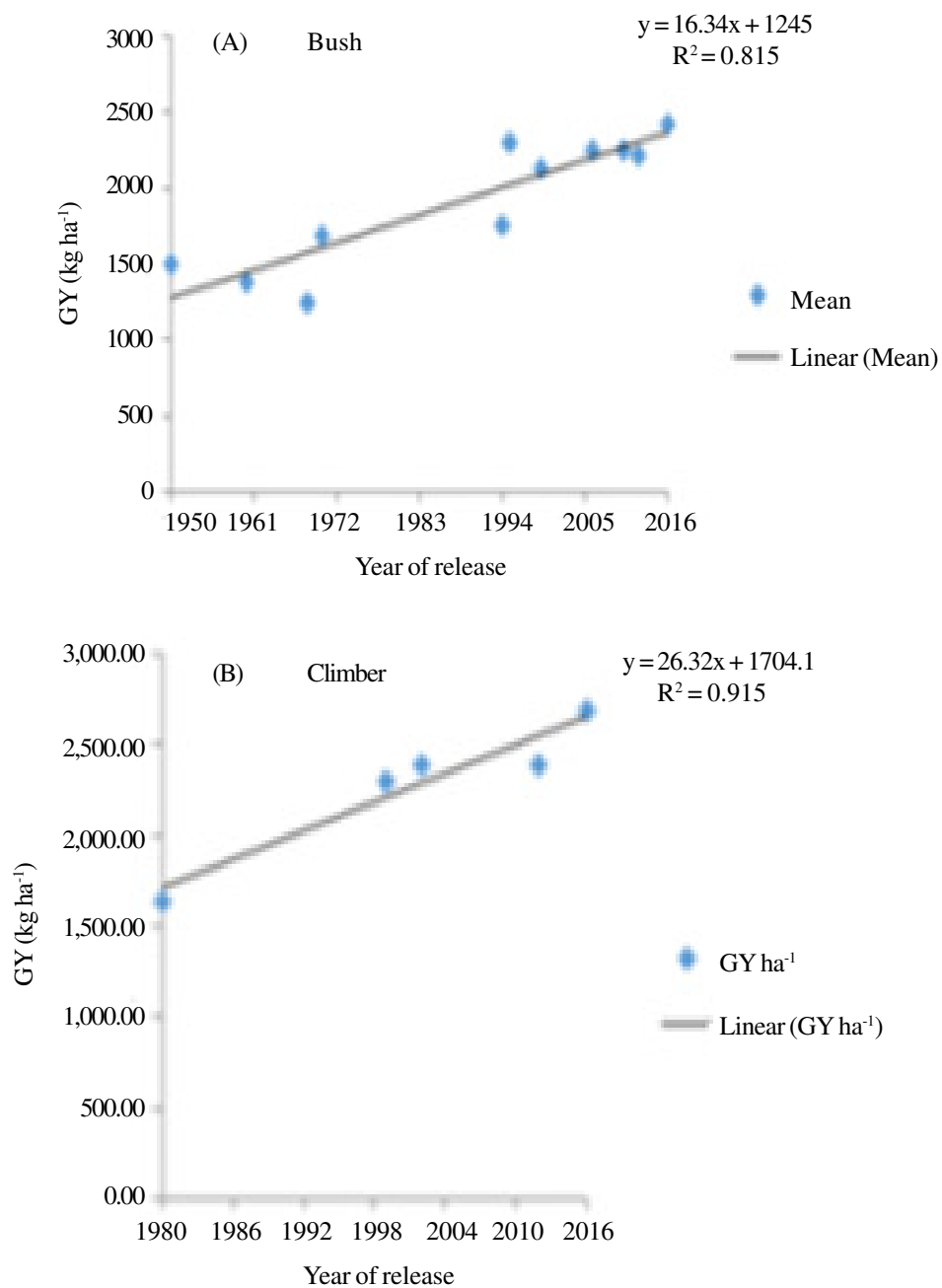


Figure 1. Relationship between mean grain yields and year of release of 40 bean cultivars. 1A - Bush beans, 1B - Climbing beans.

for a period of 56 years. For the climber types (Fig. 1B), the  $R^2$  was 0.915 indicating that change in cultivar accounted for 91.5% in yield over the 36 years. The slope of the line, that represents the annual rate of gain for bush cultivars was estimated to be  $16.3 \text{ kg ha}^{-1} \text{ year}^{-1}$ , and was significantly different from zero ( $P < 0.001$ ). The estimated annual rate of gain in yield for climbers was  $26.3 \text{ kg ha}^{-1} \text{ year}^{-1}$  ( $P < 0.05$ ), indicating rate of progress over the period. The yield ranged from  $1641.3 \text{ kg ha}^{-1}$  for the Sugar Local released in 1980, to  $2687.2 \text{ kg ha}^{-1}$  for NAROBAN 4C and Naroban 5C released in 2016. These results indicate progressive yield increase among climbing type over time, with the highest yielders being NAROBAN4C and NAROBAN5C, with a mean of  $2687.83 \text{ kg ha}^{-1}$  or 63.9% higher than the local checks (Sugar Local). There were no improved cultivars released from 1980 until 1999 when cultivars NABE 7C, NABE 8C, NABE 9C and NABE 10C, which showed 39.52% higher yield than the 1980 released cultivar were released. The most recent released cultivars

in 2016, yielded 24.38% more than the cultivars released in 1999 (Table 4). These results suggest existence of considerable genetic variability in the bean germplasm in Uganda to facilitate more genetic gain through selection. The annual relative genetic gain for agronomic traits for both types of beans is presented in Table 5.

#### Harvest index and grain yield per plant.

The annual rate of change in harvest index for the bush types was 0.108, with a  $R^2$  value (0.47); indicating a poor fit for the model as years progressed (Table 5). This was explained only by 47% of the total variation in the model, which suggested that the harvest index did not increase steadily in the bush type cultivars. Similar results were observed in the climbing types, indicating that the harvest index was not very useful as a selection index.

There was an increase in yield per plant per year in bush type of 0.048 g, which was significantly ( $P < 0.05$ ) different from zero; though with  $R^2$  value as low as 0.46, indicating a poor fit for the model (Layden, 2020).

TABLE 5. Estimates of annual relative gain for agronomic traits for bush and climbing type beans cultivars released in Uganda during 1960 -2016 period

Traits	Bush		Climber	
	b	$R^2$	b	$R^2$
GY ha <sup>-1</sup>	16.3***	0.81	26.33**	0.92
HI	0.108*	0.47	0.11	0.47
BY ha <sup>-1</sup>	11.83***	0.83	43.4*	0.82
GYP <sup>1</sup>	0.048*	0.46	0.53	0.57
SW	0.031	0.026	0.433*	0.75
NPP	0.0075	0.15	0.24	0.59
NSP	0.0036	0.05	0.01	0.13
PH	0.053*	0.35	0.85	0.37
MAT	0.08	0.24	0.34*	0.5
50%F	-0.0087	0.006	0.13	0.5

GY ha<sup>-1</sup> = grain yield per ha, HI = harvest index, BY ha<sup>-1</sup> = biomass yield per ha, SW = hundred seed weight, NPP = number of pods per plant, NSP = number of seed per plant, PH = plant height in cm, MAT = days from planting to physiological maturity, 50%F = days from planting to 50% flowering, b = slope of the regression equation,  $R^2$  = coefficient of determination for the model

However, the results indicated that yield per plant increased as a result of breeding. Similar results where an increase in yield per ha resulted from increased yield per plant were reported by Barili *et al.* (2016) in haricot beans. For the climbers, however, the slope was not significantly different from zero, suggesting that breeding did not significantly change the yield per plant.

**Hundred seed weight.** The slope for the climbing bean types was 0.433 at ( $P < 0.05$ ), with an  $R^2$  value of 0.75; indicating a good fit for the model (Table 5). This suggests an increase in the hundred seed weight of 0.433 g per year as a result of breeding over decades. The large seeded grains had higher 100 seed weights and this translated into higher yield per plant and per hectare; indicating the importance of 100 seed weight as a selection criterion by the bean breeding programmes, for the climbing types. The bush types' slope of the regression line was not significantly different from zero and thus the  $R^2$  was very low (0.026); suggesting that years of selection for yield did not change the hundred seed weight in the bush types.

**Number of pods and seeds per plant.** The slope of the regression line for number of pods per plant was 0.008 and with  $R^2 = 0.15$ , suggesting that selection of improved cultivars did not lead to a significant increase of this trait.

The slope of the regression line for the bush and climbing types was 0.0036 and 0.01, respectively; and the  $R^2$  0.05 and 0.13, respectively. This suggests that selection for high yielding cultivars over time did not affect this character for both the bush and climbing types.

**Plant height.** A very low but significant annual change in plant height (0.035 cm/per year) ( $P > 0.05$ ) was observed with a very low  $R^2$  (0.35). This suggests that breeding along this period contributed dismally to change the plant height of both cultivars. A significant

( $P < 0.05$ ) increase in plant height of 0.053 cm per year in bush types was observed, which was associated with increase in biomass.

**Days to 50% flowering.** The estimated regression line for days to 50 percent flowering was 0.0087 and 0.13 for bush and climbing types, respectively. Evidently, it was very low, indicating that improvement in grain yield did not influence the days to flowering.

**Days to 95% physiological maturity.** For the climbing bean types, the estimated b value was 0.34 at ( $P < 0.05$ ) and  $R^2$  was 0.5, indicating that there was a gradual increase in the days to physiological maturity of 0.34 days per year, resulting from the breeding effort. However, in the case of the bush types, the slope was 0.08 with a low  $R^2$  of 0.24. This suggests that selection for improved grain yield did not lead to an increase in the days to physiological maturity.

**Association among the different traits.** The results of relationships of various traits within bush types and climbing types and with year of release are presented in Table 6.

**Correlations among traits.** Among climbing types, biomass yield was significantly and positively correlated with grain yield per plant and grain yield per ha ( $P < 0.05$ ,  $r = 0.87$ ); and with grain yield per ha ( $P < 0.01$ ,  $r = 0.98$ ). For bush types, biomass yield was significantly and positively correlated with grain yield per plant and grain yield per ha ( $P < 0.05$ ,  $r = 0.59$ ) and with grain yield per ha ( $P < 0.01$ ,  $r = 0.80$ ) and harvest index ( $P < 0.5$ ,  $r = 0.80$ ). Biomass yield was positively and significantly correlated with year of release ( $P < 0.05$ ,  $r = 0.95$ ); indicating that breeding for high grain yield was accompanied by an increase in the biomass in the new releases.

**Contribution of each trait to the yield improvement.** Eighty two percent yield improvements observed was explained by biomass and number of pods per plant among

TABLE 6. Pearson correlation coefficient for different traits, the bush type beans (lower matrix) and climbing types (upper matrix)

Traits	50%F	BY ha <sup>-1</sup>	GYP	GY ha <sup>-1</sup>	HI	MAT	NPP	NSP	PH	SW	YoR
50%F		0.84	0.58	0.83	0.97**	-0.92	0.57	0.77	0.6	0.35	0.68
BY ha <sup>-1</sup>	0.28		0.87*	0.98**	-0.88*	-0.91	0.76	0.65	0.84	0.78	0.90*
GYP	-0.42	0.59*		0.84	-0.59	-0.64	0.88*	0.7	0.83	0.86*	0.75
GY ha <sup>-1</sup>	0.13	0.88***	0.64*		-0.84	-0.94	0.81	0.6	0.73	0.8	0.95**
HI	0.04	0.59*	0.54	0.80**		0.92*	-0.49	-0.7	-0.71	-0.41	0.7102
MAT	0.34	0.67*	0.38	0.67*	0.41		-0.66	-0.57	-0.59	-0.58	-0.89
NPP	-0.45	0.20	0.66*	0.47	0.57	0.30		0.65	0.51	0.77	0.76
NSP	0.699*	-0.06	0.77**	0.16	0.16	0.11	0.72*		0.62	0.26	0.35
PH	0.59	0.70**	0.06	0.72**	0.50	0.52	0.02	0.49		0.68	0.6
SW	0.86***	0.04	0.58*	0.67	0.08	-0.02	0.55	0.82***	0.46		0.86*
YoR	0.0798	0.913	0.68*	0.90***	0.68**	0.4953	0.3927	-0.227	0.59	0.16	

\*, \*\*, \*\*\* = Significant at  $P < 0.05$  and  $P < 0.01$ , respectively. • = Abbreviations: Days to fifty percent maturity, BY ha<sup>-1</sup> = biomass in kg per hectare, GYP = grain yield per plant, HI = harvest index, MAT = days to ninety five percent maturities, NPP = number of pod per plant, NSP = number of seed per pod, PH = plant height, SW = hundred seed weight, YoR = year of release

TABLE 7. Regression coefficients and coefficients of genetic determination from stepwise regression analysis of mean grain yield on other traits

Bean type	Independent variables	b	R <sup>2</sup>
Bush	Biomass yield kg ha <sup>-1</sup>	0.51***	0.59
	Harvest Index	40.68***	0.11
Climber	Biomass yield kg ha <sup>-1</sup>	0.34*	0.82
	Number of pod per plant	10.2	0.0074

\*, \*\*\* significant at P = 0.05, 0.001, respectively, b = regression coefficient, R<sup>2</sup> = coefficient of genetic determination

climbing types; while for bush beans 75% of grain yield contribution was accounted for by biomass and harvest index (Table 7).

The results of the study implicated biomass as the most important trait that had registered substantial change in the improvement of grain yield, suggesting that it was a better selection index for improving bean crop seed yield than other traits in both types.

### CONCLUSION

The bean programme in Uganda has achieved considerable gains in improving yield and associated characters during the period of 1960 to 2016 through associated parallel increase in biomass production, harvest index, grain yield per plant in bush types and biomass, hundred seed weigh and maturity period for climbing types.

### ACKNOWLEDGMENT

The research was funded by the Alliance for Green Revolution in Africa (AGRA) and College of Agricultural and Environmental Sciences, Makerere University provided research facilities while the National Crop Resources Research Institute of Uganda provided genetic materials, some of the research sites and research logistics.

### REFERENCES

- Barili, L.D., Vale, N.M., Moura, L.M., Paula, R.G. and Silva, F.F. 2016. Genetic progress resulting from forty-three years of breeding of the carioca common bean in Brazil. *Genetics and Molecular Research* 15(3): gmr.15038523. <http://dx.doi.org/10.4238/gmr.15038523>
- Broughton, W.J., Hernandez, G., Blair, M., Beebe, S., Gepts, P. and Vander Leyden, J. 2003. Beans (*Phaseolus* spp.) - Model food legumes. *Plant Soil* 252:55-128
- CIAT. 2008. Impact of bean production in Uganda National Socio-economic. Working Paper No. 1, Entebbe, Uganda. pp. 4-10.
- CIAT. 2014. Impact of bean research in Rwanda and Uganda, brief no. 46, Independence science and partnership council. pp. 2-4.
- Evans, L.T. and Fischer, R.A. 1999. Yield potential: Its definition, measurement and significance. *Crop Sciences* 39:1544-1551
- FAOSAT. 2015. National gender profile of agriculture and rural livelihoods. Available at <http://www.fao.org/uganda>.
- Gomez, K. and Gomez, A. Statistical Procedures for Agricultural Research 2<sup>nd</sup>ed. A Wiley Interscience Publication. John Wiley and Sons. New York. Chichester, Brisbane. Toronto, Singapore. 680pp.

- Leakey, C.L.A. 1970. The improvement of beans (*Phaseolus vulgaris*) in East Africa. Crop improvement in East Africa. London, the Commonwealth Agricultural Bureaux. pp. 98-128.
- Layden, K. 2020. Basic principles of genetic gain and feasibility of on-farm estimation. *Creative components* 523:19 - 22. <https://lib.dr.iastate.edu/creativecomponents/523>
- Mukayiranga, A. 2019. Analysis of genetic diversity and progress made in bean breeding in Uganda. MSc. Thesis, Makerere University, Kampala, Uganda. 85pp.
- UBOS. 2015. Uganda Bureau of Statistics. Statistical abstract available at <https://www.Ubos.org.Ug>