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Environmental effects on yield and agronomic traits of common bean (*Phaseolus vulgaris L.*)

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) demand is increasing with an alarming rate around the world, especially in Latin America, Africa, and Asia. Therefore, increased bean yield per hectare is the best way to meet the world demand rather than expansion of area under cultivation. The objectives of this experiment were to determine the genotypic variations for green bean and dry seed yield and magnitude of genotype x environment interaction effects on yield and yield components of common bean. Thirteen genotypes were planted during the 1992, 1994, and 1995 growing seasons. Genotypes were evaluated for green pod and seed yield and yield components at R7 and R9 growth stages. Years differed significantly for all recorded parameters at both R7 and R9 stages. Genotypes and genotype x year interaction were also differed significantly for most measured parameters at both stages. The genotype Eagle showed the highest green pod yield, while Branco and Blue Ridge ranked second and third, respectively when averaged over the three years. Number of pods plant^{-1}, hundred pod weight and pod length were positively and significantly correlated with green pod yield. Number of pods plant^{-1} showed the highest correlation ($r = 0.61^{**}$) with green pod yield. All the recorded parameters were positively significantly correlated with dry seed yield. Plant height was negatively correlated with seed size, number of seeds plant^{-1} and seed weight plant^{-1}. Number of pods plant^{-1} was positively correlated ($r = 0.51^{**}$) and seed size exhibited highest correlation value ($r = 0.48^{**}$) with seed yield. Seed size and number of pods plant $^{-1}$ can be effectively used for indirect selection of green pod yield and dry seed yield of common bean.

Key words: Common bean, *Phaseolus vulgaris*, yield, growth stage.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the principal source of dietary protein, vitamins and minerals for more than 500 million people in Latin America and Africa (FAO, 1991; CIAT, 1992). Common bean is grown for its green leaves, green pods, and green and/or dry seeds. Dry leaves, threshed pods, and stalks are fed to animals and used as fuel for cooking, especially in developing countries of Africa and Asia (Sirbelnagel et al., 1991). Beans are a major horticultural crop in the USA, where crop

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efficiency in acquiring and using water and nutrients is of interest as a component of sustainable agriculture (Jonathan and Beem, 1993).

Bean production has to be increased by about 42% in Latin America and 75% in Africa to satisfy the expected demand (Janssen, 1989). The projected current demand in China alone is 4.3 million tons, an increase of 22.8% compared to 1989 where the demand was 3.5 million tons (World Bank, 1989). Bean production in the developing countries is often on marginal land, and few developing countries have significant reserves of arable land that can be exploited to bean cultivation. Increased yield per hectare is the best way to meet the world demand rather than expansion of area under cultivation (Xiaolong Yan et al., 1995).

Average bean yields in most developing countries are <20% of the yield potential (CIAT, 1991), which indicates that substantial improvement in bean could be realized by increasing yields per unit land area. Increase in productivity can be attributed to genetic gains, greater use of production inputs, better agronomic practices, and more favorable growing environments. It is the combination of all these factors which provide maximum yield per unit of cropped land.

The purpose of most crop breeding programs is to increase and/or stabilize the harvestable yield per unit of land area grown at a production cost which maximizes returns to growers (Sirbelnagel et al., 1991). The primary objective of many plant breeders is the development of genotypes that are consistently high yielding over a range of environments. Genotype x environment interactions can hinder progress from selection by masking genotypic effects (Comstock and Moll, 1963). Genotype x environment interactions are often described as inconsistent differences among genotypes from one environment to another. The inconsistency could be due the difference in responses of the same set of genes to different environments and the expression of different sets of genes in different environments (Falconer, 1952; Robertson, 1959; Yang and Baker, 1991).

Yield of common bean has bean negatively associated with seed size (White and Gonzalez, 1990; White et al., 1992). However, positive relationships where reported between soybean, *Glycine max* (L.) Merr. seed size and yield (LeRoy et al., 1991; Tinius et al. , 1991), and in favabean, *Vicia faba* L. (Dantuma et al., 1983). On the other hand, Mebrahtu et. al. (1991) reported that number of seeds plant^{-1} and number of pods plant^{-1} were the most important components of bean seed yield. The objectives of this study were to determine: a) the genotypic variations for green bean and dry seed yield and b) the magnitude of genotype x environment interaction effects on yield and yield components of common bean.

MATERIALS AND METHODS

Thirteen common bean genotypes were planted in four-row plots arranged in randomized complete block design with four replications during 1992-1995. However, no substantial yield was harvested in 1993, therefore, results of the other three years are only reported. The experiments were conducted on Abell Sandy loam (fine loamy mixed, Theramic Aquatic Haplidults) soil, at Randolph Research Farm of VSU, Petersburg, Virginia. Each four-row plot was 3 m long, with 75 cm spacing between rows. A seeding rate of 23 seeds m^{-1} of row was used. Following soil test recommendations, 200 kg ha^{-1} P and K fertilizer was applied to the soil. Trifluralin herbicide was incorporated into the soil prior to planting at the recommended rate.

TABLE 1. Combined mean square analysis of variance for green pod and seed yields and yield components harvested at green pod stage (R7) and dry seed growth stage (R9).

Source of Variance	dF	GPY	SY	NGPP^{-1}	HPW	HSW	SWP^{-1}	GPL	DPL	Plant Height
		Kg ha^{-1}			g			cm		
Year (Y)	2	1715^{**}	59.4^{**}	703.2^{**}	616893^{**}	514^{**}	1125^{**}	18.5^{*}	59.7^{**}	530^{**}
Rep (Y)	9	144	0.9	62.5	16572	9.3	58.7	2.5	2.7	35.7
Genotype (G)	12	82^{*}	2.1^{ns}	79.5^{**}	28036^{**}	44.0^{ns}	81.9^{ns}	11.6^{**}	7.2^{**}	132^{ns}
Y X G	24	75^{*}	1.4^{**}	32.5^{*}	10579^{*}	22.1^{**}	473^{**}	1.9^{*}	1.1^{**}	54.8^{**}
Error	108	45	0.6	18.1	6094	5.0	15.8	1.5	1.9	23.4

*, ** Significant at 0.5 and 0.01 probability levels, respectively.
ns = not significant.
GPY = Green pod yield, SY = seed yield, NGPP = Number of green pods/plant; HPW = Hundred pod weight; SWP = Seed weight per plant; GPL = Green pod length; DPL = Dry pod length

Genotypes were evaluated at green pod (R7) and dry seed (R9) stages for various agronomic parameters (Robert Hall 1991). One meter of each of the two center rows was harvested at both stages. At R7, the harvested materials were put into plastic bags and brought to the laboratory. Five plants from each above ground harvested plot were randomly selected and, plant height, number of pods plant^{-1}, hundred pod weight, pod length and green pod yield were recorded as described by Nienhius and Singh (1985). The pods from each harvested plot were pulled manually and the weight was recorded as green pod yield. At R9 stage, number of pods plant^{-1}, pod length, number of seeds plant^{-1}, and hundred seed weight, were recorded from the sampled five plants and seed yield was recorded after threshing the remaining harvested materials. Data were analyzed by Statistical Analysis System (SAS for Microsoft Windows, Release 6.1, 1994) as randomized complete block design. After testing the homogeneity of error variances, combined data over years were analyzed. Genotypes were considered as fixed effects and years as random effects. Least significant differences (LSD) at 5 % probability level were used to compare means.

RESULTS AND DISCUSSION

Green Pod Stage (R7):

The analysis of variance indicated significant year effect for all parameters measured, suggesting that multiple year testing is required to make appropriate selection from the tested parameters (Table 1). Significant genotypic effects also were observed for all measured parameters at R7 stage with the exception of plant height. These results suggest that genetic variability exists among the genotypes to make selection and improvement through hybridization. Furthermore, genotype x year interactions were significantly different for all the parameters. These significant interactions indicated that the performance of genotypes differed from one year (growing season) to another.

The overall genotypic green pod yield mean was 19,528 kg ha^{-1}, and ranged from 14,821 kg ha^{-1} for VB90-3 to 22,768 kg ha^{-1} for Eagle followed by Branco and Blue Ridge. Due to the weather that prevailed during most of the early growing stages in 1994, the mean green pod yield of the best performers was reduced by 32-62% (Table 2). Blue Ridge had the highest 100 green pod weight when averaged across the years

TABLE 2. Mean green pod and dry seed yield (kg ha^{-1}) of common bean genotypes during three growing seasons at Randolph Research Station, Petersburg, Virginia

	YEAR				YEAR			
Genotypes	1992	1994	1995	Grand	1992	1994	1995	Grand
	Green Pod			Mean	Dry Seed			Mean
Eagle	22063	15844	30398	22768	1190	3954	901	1839
Wrangler	26740	11078	24195	20671	2229	3711	1289	2410
Hialeah	24616	10980	20748	18782	2355	4159	907	2474
Prosperity	26254	15280	22485	21339	2685	2328	406	1806
Mustang	21757	13493	21077	18776	2240	2095	851	1695
Blue Ridge	22550	21130	23753	22478	1545	4008	1307	2286
Acclaim	26103	10399	22941	19814	2116	3097	1616	2276
Delta	18700	12845	16478	16008	1584	3062	1228	1958
Branco	29267	9433	29407	22702	2067	2894	1269	2076
Strike	24167	8940	28643	20583	1997	3071	810	1956
Roman II	26633	10157	19750	18847	1704	2046	1217	1655
Pinto III	11257	18370	19189	16272	1950	5072	2300	3107
VB90-3	15410	9714	19339	14821	3059	3939	1593	2864
Grand Mean	22732	12897	22945	19528	2056	3354	1207	1527
LSD (0.05)	12076	10907	7461	10148	1275	1310	741	625

followed by Roman II and Delta (Table 3). However, in the individual years, the 100 pod weight of Roman II which was ranked the highest in 1992 was reduced by 28% in 1994. Similarly, Wrangler which ranked third in 1992 was reduced by 16% in 1994. The cultivar Prosperity had the longest green pod length when averaged across years (Table 4). Green pod length ranged from 14.61cm for Prosperity to 11.02 cm for breeding line VB90-3. Prosperity ranked first in 1992 and 1995, and second in 1994. The early dry season of 1994 did not affect significantly the green pod length.

The cultivar Blue Ridge ranked the highest in number of pods plant^{-1} followed by Acclaim and Eagle when averaged across the years (Table 3). In individual years, Eagle, Prosperity and Blue Ridge were ranked first, second and third, respectively in 1992. However, number of pods plant^{-1} was reduced by 54%, 49% and 34%, respectively in 1994. Blue Ridge ranked among the highest in green pod yield, hundred-pod weight, green pod length, and number of pods plant^{-1} in overall genotypic ranking.

The simple linear correlations at green pod stage for the genotypes are reported in Table 5a. Among the parameters measured, number of pods plant^{-1}, hundred pod weight, and pod length were positively and significantly correlated to green pod yield. Number of pods plant^{-1} showed the highest correlation ($r = 0.61^{**}$) with green pod yield. Plant height was negatively correlated to hundred-pod weight, which was the parameter second to number of pods plant^{-1} correlated to green pod yield. This suggests that even though plant height was not directly and negatively correlated to green pod yield, it will negatively affect hundred-pod weight, which is directly correlated to green pod yield. Plant height was also negatively correlated to seed size and pod length.

TABLE 3. Mean of hundred-green pod weight (HPW) and mean number of pods plant^{-1} (NGPP^{-1}) of common bean genotypes during three growing seasons and harvested at green pod stage (R7) at Randolph Research Station, Petersburg, Virginia

Genotypes	YEAR			Grand	YEAR			Grand
	1992	1994	1995		1992	1994	1995	
	HPW (g)			Mean	NGPP^{-1}			Mean
Eagle	437	498	607	514	19.70	9.05	16.60	15.12
Wrangler	492	412	706	537	17.75	8.10	10.90	12.25
Hialeah	470	533	646	549	16.95	9.00	16.60	13.96
Prosperity	471	468	616	519	19.45	9.95	15.75	14.18
Mustang	407	458	535	467	16.00	9.80	16.25	14.02
Blue Ridge	498	499	769	589	19.45	12.90	19.75	17.37
Acclaim	433	422	730	535	17.05	8.90	19.20	15.05
Delta	477	494	731	567	12.80	8.15	9.25	10.07
Branco	461	472	548	493	14.55	9.40	20.90	14.95
Strike	406	346	559	437	18.20	7.00	18.40	14.53
Roman II	588	422	728	579	16.00	8.40	8.90	11.10
Pinto III	437	384	630	484	9.20	11.35	13.25	9.32
VB90-3	370	437	553	453	8.15	12.05	8.50	9.33
Grand Mean	457	451	643	517	15.79	9.04	14.94	13.26
LSD (0.05)	102	135	117	118	5.5	7.0	7.2	6.6

Dry Seed Stage (R9):

Mean square analysis of variance for dry seed yield and yield components at dry seed stage (R9) are shown in Table 1. The genotypes showed the highest mean dry seed yield in 1994 compared to the other two years (Table 2). The high seed yield of 1994 could be due to compensatory growth after plants received adequate moisture later in the growing season. However, 1995 was the lowest in dry seed yield among the three years. The overall genotypic dry seed yield was 1,527 kg ha^{-1}, and ranged from 1,655 for Roman II to 3,107 for Pinto III. The genotype Pinto III had the highest dry seed yield followed by VB90-3 and Hialeah, while Roman II had the lowest when averaged over the three years. The breeding line VB90-3 which yielded lowest in green pod yield ranked second highest in dry seed yield over the years. In 1992, VB90-3 ranked first in dry seed yield, this yield was decreased by 48% in 1995. Similarly, Prosperity and Hialeah, which ranked second and third in 1992, their yields were reduced also by 85% and 51%, respectively. The overall genotypic number of pods plant^{-1} was 11.1, and ranged from 13.6 for Hialeah to 7.6 for Roman II. Hialeah was ranked first in 1992 followed by Strike and Eagle. While in the succeeding years, the number of pods plant^{-1} was significantly low (Table 3). The overall genotypic mean hundred seed weight mean was 23.6 grams, and ranged from 27.5 for Roman II to 19.6 for Branco (Table 6). Roman II had the highest hundred-seed weight followed by Pinto III and VB90-3. Averaged across the years, VB90-3 had the highest number of seeds plant^{-1} followed by Acclaim and Strike. (Table 4). VB90-3 ranked first in 1992 and 1994 and second in 1995 for number of seeds plant^{-1}. The three top dry seed yielding genotypes Pinto111, VB90-3 and Hialeah, where among the lowest yielders in green pod yield.

TABLE 4. Mean green pod length (GPL) and number of dry seeds plant^{-1} (NDSP^{-1}) of common bean genotypes during three growing seasons at Randolph Research Station, Petersburg, Virginia

Genotypes	YEAR			Grand Mean	YEAR			Grand Mean
	1992	1994	1995		1992	1994	1995	
	GPL (cm)				NDSP^{-1}			
Eagle	12.37	12.97	13.82	13.06	17.9	58.5	44.6	40.3
Wrangler	12.02	12.52	13.50	12.68	33.4	59.2	58.1	50.3
Hialeah	13.30	14.45	14.13	13.96	35.3	48.1	72.5	52.0
Prosperity	14.81	14.37	14.64	14.61	40.3	34.1	34.5	36.3
Mustang	11.96	11.95	14.12	12.68	33.6	42.6	74.6	50.3
Blue Ridge	12.82	12.75	13.84	13.14	23.1	40.9	78.5	47.5
Acclaim	11.38	13.22	13.03	12.55	31.7	54.6	79.1	55.2
Delta	13.23	12.15	13.99	13.13	23.8	39.8	48.5	37.4
Branco	12.45	11.29	13.22	12.32	31.0	39.9	72.8	47.9
Strike	12.26	12.35	13.69	12.77	22.5	51.6	84.7	52.9
Roman II	11.70	10.32	12.51	11.51	25.5	22.1	32.5	26.7
Pinto III	10.49	12.15	11.84	11.49	29.2	56.2	53.5	46.3
VB90-3	9.80	12.05	11.20	11.02	45.9	91.0	83.5	73.5
Grand Mean	12.20	12.50	13.35	12.68	30.2	49.1	62.9	47.4
LSD (0.05)	1.35	2.24	1.75	1.78	19.5	22.6	29.8	13.0

Similarly, Pinto III and VB90-3 ranked the lowest in R7 growth stage for hundred green pod weight, number of pods plant^{-1} and pod length (Tables 3, and 4). This suggests that different genotypes are to be selected for R7 and R9 productions. This idea was supported by Spearman's Rank Correlation between R7 and R9 which was negative but not significant, indicating that breeders have to select and breed for individual components separately.

The simple linear correlations at dry seed stage for the genotypes are reported in Table 5b. Most of the parameters recorded were positively and significantly correlated with dry seed yield. Plant height was the only parameter that was negatively correlated with seed size and number of seeds plant^{-1}. Among the parameters measured, number of pods plant^{-1} and seed size showed the highest correlations with seed yield. Similar correlations were observed between number of pods plant $^{-1}$, and seed size with green pod yield (Table 5a). However, White and Gonzalez (1990) and White et. al. (1992) reported negative association of seed size with common bean yield. The negative relationship of seed size and yield potential of common bean runs counter to the observation that, within a given seed lot, plants originating from larger seeds perform better than plants originating from small seed in common bean (Clark and Beck, 1968; Sangakkara, 1989). This suggests that some genetic factor associated with large seed size, rather than large seed size itself, may be responsible for the lower yield of large seeded cultivars. Secondly, yield differences associated with seed size in common bean may be an artifact of differences in regions of domestication between large and small-seeded cultivars. Genotypes originated from the Andean highlands are predominantly large seeded, while genotypes of Meso-American background are predominantly small seeded and are grown mainly in warmer environments (Laing et al., 1984;

TABLE 5a. Simple linear correlation coefficient analysis among five agronomic traits, of bean genotypes harvested at green pod growth stage (R7).

Agronomic traits	Yield ($kg\ ha^{-1}$)	Height (cm)	Pods $plant^{-1}$ Number	100 pod weight (g)	Pod length (cm)
Yield	1.0	0.02	0.61**	0.40**	0.29**
Height		1.0	-0.10	-0.25**	-0.14
Pods $plant^{-1}$			1.0	0.23**	0.25**
100 pod weight				1.0	0.42**
Pod length					1.0

*, ** Correlation coefficient significantly different at 0.05 and 0.01 probability levels, respectively.

TABLE 5b. Simple linear coefficient analysis among four agronomic traits, of bean genotypes harvested at seed dry seed stage.

Agronomic traits	Seed yield ($kg\ ha^{-1}$)	Pods $plant^{-1}$ Number	100 seed weight (g)	Seeds $plant^{-1}$
Yield	1.0	0.51**	0.48**	0.18*
Pods $plant^{-1}$		1.0	-0.24**	0.58**
100 seed weight			1.0	0.05
Seeds $plant^{-1}$				1.0

*, ** Correlation coefficient significantly different at 0.05 and 0.01 probability levels, respectively.

Singh et al., 1991). Thus, the observed differences in yield between large and small-seeded genotypes may be a function of cultivar adaptation associated with region of domestication. White and Gonzalez (1990) offered an alternative explanation, that cultivar seed size is correlated with cell size in the seed and in the rest of the plant, and that cell size may have an important influence on growth and yield. Similar to soybean as reported by Clark and Beck (1968) and Sangakkara (1989), our data show that there is a strong positive correlation between seed size and dry seed yield in the genotypes tested in Virginia.

SUMMARY AND CONCLUSIONS

Significant differences were observed for all the recorded parameters at both green pod and dry seed growth stages. Genotypes x year interactions differed significantly for all parameters at R7 stage, and genotypes also differed for all parameters measured except for plant height. However, genotypes differed significantly for only number of seeds $plant^{-1}$ and pod length at R9 stage. The overall genotypic green pod yield was 19,528 $kg\ ha^{-1}$ and ranged from 14,821 $kg\ ha^{-1}$ for VB90-3 to 22,768 $kg\ ha^{-1}$ for Eagle, while dry seed yield genotypic mean was 1,527 $kg\ ha^{-1}$, and ranged from 1,655 for Roman II to 3,107 for Pinto III. The genotypes Eagle and Pinto III had the highest green pod and dry seed yields respectively. Blue Ridge ranked the highest in green pod yield, hundred pod weight, green pod length, and number of pods $plant^{-1}$ over the years. The genotypes had the highest green pod yield in 1995 and the highest dry seed yield in 1994 compared to the other two years. The three top dry seed yielding genotypes Pinto III, VB90-3 and Hialeah, where among the lowest yielders in green pod yield. Similarly, Pinto III and VB90-3 ranked the lowest in R7 growth stage for hundred green pod weight, pod length and number of pods plant^{-1}. This suggests that different genotypes are to be selected for green pod (R7) and dry seed yield (R9) productions.

Among the parameters measured, number of pods plant^{-1}, hundred-pod weight and pod length were positively and significantly correlated with green pod yield. Number of pods plant^{-1} showed the highest correlation (r = 0.61**) with green pod yield. All the recorded parameters were positively and significantly correlated with dry seed yield. Number of pods plant^{-1} (r = - 0.51**) and seed size (r = 0.48**) showed the highest correlations with dry seed yield among the parameters measured at R9 stage. Similar results were observed when genotypes were harvested at green pod stage. However, our results contradict to the results of White and Gonzalez (1990) and White et al. (1992) who reported negative association between seed size and common bean yield. Our data suggested that the two parameters, seed size and number of pod plant^{-1} can be used effectively for indirect selection of green pod and seed yield in common bean.

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