Heritabilities and phenotypic correlations of morphological traits of beans[1]

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ABSTRACT

Indeterminate bean (*Phaseolus vulgaris* L.) lines derived from crosses between small-seeded indeterminate and large-seeded determinate genotypes were used for estimating the heritabilities and phenotypic correlations for seed yield and morphological traits. The F_2 generation of six bean populations was planted at the Fortuna Substation, Juana Díaz, Puerto Rico in October 1984. Seed yield per plant, number of branches per plant, plant height, node number per plant, biological yield, and apparent harvest index were measured for 50 indeterminate plants selected at random from each population. Fifty plant rows of each population were planted in February 1985 at the Fortuna Substation, and in March 1985 on a small farm in the Constanza valley of the Dominican Republic. Narrow sense heritabilities were estimated with parent-offspring regressions of the F_2 and F_3 generations, and phenotypic correlations were estimated with means of the F_3 lines. The indeterminate F_3 lines had greater plant height and fewer nodes than their indeterminate parents. Biological yields, harvest indexes and number of branches of the F_3 plants were generally equal to or less than those of their indeterminate parents. Greater branch and node number and greater plant height, biological yield, and harvest index were associated with greater seed yield. Narrow sense heritabilities (NSH) of morphological traits were generally low to intermediate. Since NSH of the morphological traits were no greater than NSH of seed yield, replicated advanced generation yield trials still appear to be the most effective approach for identifying large-seeded indeterminate bean lines with greater seed yield potential.

RESUMEN

Heredabilidad y correlaciones fenotípicas de las características morfológicas de las habichuelas

Líneas indeterminadas de habichuela (*Phaseolus vulgaris* L.) derivadas de cruces entre genotipos determinados con semillas pequeñas y genotipos determinados con semillas grandes se usaron para estimar las heredabilidades y las correlaciones fenotípicas para rendimiento de semilla y las características morfológicas. Seis poblaciones F_2 de habichuela se sembaron en la Subestación de Fortuna, Juana Díaz, Puerto Rico en octubre de 1984. Se cuantificó el peso de la semilla, el número de ramas,

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la altura, el número de nudos, el rendimiento biológico y el índice de cosecha aparente por planta en 50 plantas indeterminadas seleccionaadas al azar en cada población. Se sembraron 50 surcos de cada población en la Subestación de Fortuna en febrero de 1985 y en una pequeña finca en el Valle de Constanza de la República Dominicana en marzo de 1985. Se estimaron heredabilidades en el sentido estrecho usando regresiones padre-progenie de las generaciones F_2 y F_3 y correlaciones fenotípicas con los promedios de las líneas F_3. Las líneas indeterminadas F_3 fueron más altas y tuvieron menos nudos que los padres indeterminados. El rendimento biológico, el índice de cosecha y el número de ramas de las plantas F_3 fueron generalmente iguales o menores que los de los padres indeterminados. Un mayor número de ramas y nudos, una mayor altura, el rendimento biológico y el índice de cosecha estuvieron asociados con un mayor rendimento de semilla. Las heredabilidades en el sentido estrecho (HSE) de las características morfológicas fueron mayormente bajas o intermedias. Como las características morfológicas no tuvieron HSE mayor que el rendimento de semilla, el uso de ensayos de rendimento en generaciones avanzadas es todavía la mejor opción para identificar un mayor rendimiento en genotipos indeterminados de habichuela grande.

INTRODUCTION

Indeterminate bean (*Phaseolus vulgaris* L.) genotypes possess more yield stability than genotypes having a determinate growth habit (2, 8). Moreover, the yield potential of indeterminate beans is greater than that of determinate beans, in part, because of the development of genotypes having improved architectural traits (8). Adams (1) proposed a high-yielding architectural plant type for indeterminate beans grown in monoculture which featured a tall erect main stem with few lateral branches, a large number of nodes, short internodes, and a vigorous root system.

Since most large-seeded bean varieties grown in the Caribbean have a determinate growth habit, undesirable architectural plant traits associated with this growth habit may limit the yield potential and yield stability of beans grown in this region. Efforts to develop large-seeded indeterminate beans with improved morphological traits have been impeded by F_1 hybrid weakness in crosses of beans from different centers of domestication (4, 12). However, Kelly (7) recently reported improvement in the architectural traits of large-seeded indeterminate pinto beans with phenotypic recurrent selection.

In order to design effective methods for selecting improved morphological traits, one needs knowledge of the heritabilities of the traits and the strength of the relationships of the traits with seed yield (11). Ghaderi and Adams (5) studied the inheritance of some morphological traits related to plant architecture in small-seeded indeterminate beans. Much genetic variability for morphological traits was produced by crossing morphologically divergent parents. The authors concluded that desired plant types could be selected from these by segregating populations. Nienhaus and Singh (11) crossed bean lines of varying seed size and growth habit in a diallel fashion. Seed yield was positively correlated with nodes per branch, nodes per plant, nodes on the main stem, main stem length, and main stem internode length. General combining ability was found to be more important than specific combining ability for most morphological traits. Genotype × environment interaction also affected the expression of the morphological traits.

The objectives of this research were to measure the strength and stability of the relationship of certain morphological traits with seed yield, and to estimate the narrow sense heritabilities of these morphological traits.

MATERIALS AND METHODS

Six bean populations derived from crosses between large-seeded determinate and small-seeded indeterminate bean genotypes were used in the study. The large-seeded determinate genotypes were "Pompadour checa", 'José Beta", "8241-168A", and "Borinquen". The small-seeded, indeterminate genotypes were "H-376", "La Vega" and "PAI-92". The F_2 generation was planted in unreplicated blocks at the Fortuna Substation, Juana Díaz, Puerto Rico 20 October 1984. Rows were spaced 60 cm apart, and the space among plants within each row was approximately 10 cm. At harvest maturity, 50 indeterminate plants were selected at random from each block. Seed yield was measured as seed weight per plant. The number of branches (NB) and the number of nodes (NN) on the main stem were counted on each plant. Plant height (PH) was measured from the soil surface to the point of attachment of the uppermost pod. The dry weight of the aerial portion of the plant without leaves and petioles was used to estimate biological yield (BY). Harvest index (HI) was estimated as a ratio between seed yield and biological yield (SY/BY).

Fifty F_3 rows from each population were planted 22 February 1985 at the Fortuna Substation [soil type: Mollisol (Ultisolls)] and on 22 March 1985 on a small farm in the El Río parish, Constanza, Dominican Republic. [Soil type: Alfisols (Udalfs)]. A replication within block design was used (6). The experiment consisted of 5 randomized complete blocks with 3 replications per block. Each replication of a block consisted of 10 F_3 lines selected at random from the F_2 nursery and the two parents used to create the population. The experimental units consisted of 10 seeds planted in 1-m row lengths spaced 60 cm apart. Two bordered indeterminate F_3 plants were selected from each row. Seed yield, BY, NN, NB, PH, and HI were measured by the previously described methods.

Means of SY, BY, NN, NB, PH, and HI of the 10 indeterminate F_3 lines and their parents were determined for each population and location. Means of the F_3 lines and their parents were compared with approximate *t* tests. Phenotypic correlations between BY, NN, NB, PH, HI, and SY were calculated for each population and location with the means of the indeterminate F_3 lines. Narrow sense heritabilities were estimated for each population and location by regression of means of F_3 lines onto individual F_2 plant measurements. Since F_2 plants and their progeny were evaluated, the regression coefficients and their standard errors were multiplied by 0.67 to account for inbreeding.

RESULTS AND DISCUSSION

The seed yield of the indeterminate F_3 lines was significantly less than the seed yield per plant of their indeterminate parents (table 1). The difference between the mean yield per plant of the F_3 lines and the mean yields of the indeterminate parents was greater in the low yield environment, Constanza.

Within each population number of branches per plant were similar in the two locations (table 1). Most of the indeterminate F_3 lines produced branch numbers similar to those of their indeterminate parents. How-

TABLE 1.—*Mean seed yield, mean number of branches per plant and mean plant height of parents and F_3 lines grown at Constanza, Dominican Republic and Juana Díaz, Puerto Rico*

Population	Generation[1]	Seed yield		No. branches per plant		Plant height	
		Constanza	J. Díaz	Constanza	J. Díaz	Constanza	J. Díaz
		g/plant				*cm*	
Pompadour checa	P_1[1]	9	16	3.2	4.3	32	32
H-376	P_2	18	23	5.2	4.9	32	37
	F_3	12*[2]	17*	3.9*	3.9*	37*	54*
José Beta	P_1	10	16	3.2	5.1	24	27
H-376	P_2	19	21	5.3	4.5	32	42
	F_3	12*	17*	4.0*	4.3	31	45
Pompadour checa	P_1	9	17	3.2	4.2	29	29
La Vega	P_2	16	19	4.0	4.3	34	51
	F_3	10*	16	3.3*	3.5	40*	56
José Beta	P_1	8	16	3.1	5.7	23	26
La Vega	P_2	16	20	3.9	3.7	35	54
	F_3	13*	20	4.0	4.1	35	52
8241-168A	P_1	7	18	2.7	4.0	29	30
PAI-92	P_2	11	18	3.0	3.9	27	39
	F_3	10	14*	3.0	3.5	33*	53*
Borinquen	P_1	5	20	2.3	4.1	25	30
PAI-92	P_2	11	18	3.1	3.9	25	37
	F_3	11	20	3.2	3.8	31*	52*

[1]P_1 = determinate and P_2 = indeterminate parent.

[2] = Significantly different from the indeterminate parent at the 0.05 probability level.

ever, the indeterminate F_3 lines derived from the crosses with H-376 as a parent had fewer branches than the indeterminate parent.

The indeterminate F_3 plants at Fortuna were 15 to 20 cm taller than those at Constanza (table 1). The mean plant heights of the F_3 lines were generally equal to or greater than those of the indeterminate parents. The increased plant height of the F_3 lines, however, was not reflected in a greater number of nodes per plant (table 2). At Constanza the indeterminate F_3 plants in five of the six populations had fewer nodes than the indeterminate parent. Therefore, the greater plant height of the F_3 lines was the result of greater main stem internode length. Node numbers per plant of the indeterminate F_3 lines at Fortuna, the higher yielding environment, were similar to those of the indeterminate parent. Node number of the indeterminate F_3 plants at Fortuna was almost double the node number per plant at Constanza. However, the proportional decrease in node number at Constanza was greater for the determinate parents than for the indeterminate parents. The indeterminate lines at

TABLE 2.—*Mean node number per plant, mean biological yield per plant and mean apparent harvest index of parents and F_3 lines grown at Constanza, Dominican Republic and Juana Díaz, Puerto Rico*

Population	Generation[1]	Node no. per plant		Biological yield per plant		Apparent harvest index	
		Constanza	J. Díaz	Constanza	J. Díaz	Constanza	J. Díaz
				g			
Pompadour checa	P_1[1]	11.9	19.1	14	27	0.65	0.60
H-376	P_2	22.5	33.7	27	36	0.70	0.66
	F_3	17.6*[2]	30.9	20*	31	0.61	0.54*
José Beta	P_1	11.2	21.1	15	28	0.64	0.56
H-376	P_2	26.0	31.8	30	35	0.64	0.59
	F_3	17.5*	30.1	20*	30*	0.61	0.56
Pompadour checa	P_1	9.9	19.4	14	27	0.63	0.56
La Vega	P_2	18.1	32.7	23	30	0.70	0.63
	F_3	15.3*	27.3*	16*	29	0.63*	0.57*
José Beta	P_1	11.6	19.4	14	26	0.59	0.65
La Vega	P_2	20.0	26.3	22	32	0.70	0.63
	F_3	18.3	29.3	19	32	0.67	0.62
8241-168A	P_1	13.4	19.2	12	29	0.60	0.58
PAI-92	P_2	21.1	29.5	15	33	0.69	0.62
	F_3	13.7*	26.7	16	26*	0.61*	0.54*
Borinquen	P_1	9.5	19.3	8	29	0.60	0.63
PAI-92	P_2	22.9	25.9	16	31	0.67	0.64
	F_3	14.6*	28.7	17	34	0.63	0.58

[1]P_1 = determinate and P_2 = indeterminate parent.
[2] = Significantly different from the indeterminate parent at the 0.05 probability level.

Constanza produced as many nodes as the determinate parents at Fortuna.

Biological yields from Constanza were significantly less than biological yields from Fortuna (table 2). The biological yields of the indeterminate parents were greater than those of the determinate parents whereas the biological yields of the indeterminate F_3 lines were equal to or less than the indeterminate parents.

Since the harvest indexes of the determinate and indeterminate parents were similar, the greater seed yields of the indeterminate parents were attributed to greater biological yield (table 2). The harvest indexes of the indeterminate F_3 lines of three of the six populations were significantly less than the harvest indexes of the parents. Since apparent harvest indexes at Fortuna were lower than at Constanza, the greater yields obtained at Fortuna were attributed to greater biological yields rather than to a more efficient partitioning of photosynthate.

Positive and significant phenotypic correlations between seed yield and number of branches per plant were found for all populations (table 3). The high-yield architectural plant type proposed by Adams (1) featured a reduced number of branches. The presence of fewer branches reduces inter-plant competition when beans are grown in narrow row widths and dense plant populations. A greater number of branches per plant, however, may be a favorable trait when plant populations are sub-optimum or when environmental stress has limited main stem node number.

Number of nodes per plant was found to be positively and significantly correlated with seed yield for all populations and at both locations (table 3). A strong relationship between node number and seed yield has been reported by other researchers (1,11). Laing et al. (9) considered a node with a trifoliate leaf and a pod to be the basic building block of a bean plant.

There were positive and significant correlations between seed yield and height in five of the six populations at Constanza, the lower yielding environment (table 3). At Fortuna, three of the six populations had significant positive correlations between plant height and seed yield. A comparison of plant heights in higher and lower yield environments may provide an indirect measure of the vigor of a genotype when subjected to stress.

There were large positive phenotypic correlations between biological yield and seed yield for all populations and for both locations (table 3). Greater biological yield, however, is associated with later maturity. Therefore, selection solely on the basis of yield per plant may result in the selection of later maturity plants which may not be appropriate for local cropping systems.

Apparent harvest indexes were positively associated with greater seed yield in five of the six populations at Fortuna, but in only three of

TABLE 3.—*Phenotypic correlations between branches per plant, number of nodes per plant, biological yield per plant, plant height, apparent harvest index, and seed yield using F_3 plants of six bean populations grown at Constanza, Dominican Republic and Juana Díaz, Puerto Rico*

Population	No. of branches per plant		Plant height		Node no. per plant		Biological yield per plant		Apparent harvest index	
	Constanza	J. Díaz	Constanza	J. Díaz	Constanza	J. Díaz	Constanza	J. Díaz	Constanza	J. Díaz
Pompadour checa × H376	0.43**[1]	0.45**	0.50**	0.27*	0.51**	0.54**	0.94**	0.87**	0.10	0.30*
José Beta × H376	0.48**	0.50**	0.26	0.20	0.54**	0.29	0.95**	0.91**	0.11	0.48**
La Vega × Pompadour checa	0.43**	0.54**	0.27*	0.14	0.40**	0.65**	0.97**	0.91**	0.34*	0.52**
La Vega × José Beta	0.76**	0.33*	0.65**	0.54**	0.52**	0.51**	0.96**	0.89**	0.38*	0.28*
8241-168A × PAI-92	0.70**	0.43**	0.66**	0.26	0.71**	0.53**	0.98**	0.92**	0.33*	0.38*
PAI-92 × Borinquen	0.49**	0.05	0.44**	0.40**	0.50**	0.55**	0.98**	0.95**	−0.01	0.38*

[1]*,** Significant at the 0.05 and 0.01 probability levels, respectively.

TABLE 4.—*Narrow sense heritabilities*[1] *for seed yield, number of branches per plant, and plant height*

	Seed yield		No. branches per plant		Plant height	
Population	Constanza	J. Díaz	Constanza	J. Díaz	Constanza	J. Díaz
Pompadour checa × H-376	0.30 ± 0.02	0	0.10 ± 0.05	0	0.13 ± 0.03	0.16 ± 0.15
José Beta × H-376	0.37 ± 0.03	0.60 ± 0.04	0.17 ± 0.11	0.15 ± 0.08	0.12 ± 0.04	0.17 ± 0.05
La Vega × Pompadour checa	0.39 ± 0.03	0.34 ± 0.05	0.08 ± 0.07	0.30 ± 0.07	0.13 ± 0.04	0.18 ± 0.05
La Vega × Jose Beta	0.18 ± 0.03	0.22 ± 0.04	0.65 ± 0.09	0.15 ± 0.19	0.24 ± 0.04	0.28 ± 0.06
8241-168A × PAI-92	0.59 ± 0.03	0	0.09 ± 0.09	0.26 ± 0.07	0.37 ± 0.04	0.22 ± 0.06
PAI-92 × Borinquen	0	0	0.09 ± 0.05	0.07 ± 0.08	0	0.07 ± 0.05

[1] Heritabilities were estimated using parent-offspring regressions of indeterminate F_2 and F_3 plants of six bean populations grown at Constanza, Dominican Republic and Juana Díaz, Puerto Rico.

TABLE 5.—*Narrow sense heritabilities*[1] *for node number per plant, biological yield per plant and apparent harvest index*

	Node number per plant		Biological yield per plant		Apparent harvest index	
Population	Constanza	J. Díaz	Constanza	J. Díaz	Constanza	J. Díaz
Pompadour checa × H-376	0.35 ± 0.02	0	0.29 ± 0.02	0	0.07 ± 0.11	0.40 ± 0.17
José Beta H-376	0.49 ± 0.04	0.63 ± 0.05	0.41 ± 0.03	0.54 ± 0.03	0.16 ± 0.13	0.13 ± 0.15
La Vega × Pompadour checa	0.48 ± 0.03	0	0.31 ± 0.07	0.07 ± 0.04	0.13 ± 0.07	0.21 ± 0.09
La Vega × José Beta	0.26 ± 0.04	0.07 ± 0.05	0.15 ± 0.03	0.62 ± 0.03	0.07 ± 0.01	0.52 ± 0.01
8241-168A × PAI-92	0.13 ± 0.03	0	0.47 ± 0.03	0	0.17 ± 0.07	0.42 ± 0.08
PAI-92 × Borinquen	0.09 ± 0.02	0.20 ± 0.04	0	0	0	0.13 ± 0.07

[1]Heritabilities were estimated using parent-offspring regressions of indeterminate F_2 and F_3 plants of six bean populations grown at Constanza, Dominican Republic and Juana Díaz, Puerto Rico.

the six populations at Constanza (table 3). Since no significant negative phenotypic correlations between harvest index and seed yield were observed, it may be possible to select simultaneously for greater seed yield and higher harvest index.

Greater seed yield was not strongly related to any single trait; rather it was associated with an enhanced expression of a combination of morphological traits. Nienhaus and Singh (11) noted that selection for the enhanced expression of morphological traits should result in the correlated response for increased seed yield

Narrow sense heritabilities of all traits were low to intermediate (tables 4 and 5). Since none of the traits had narrow sense heritabilities greater than seed yield, replicated advanced generation yield trials still appear to be the most effective approach to identify bean genotypes with greater seed yield potential (10). Visual selection in early generation may be used to select plants with many branches and a large number of nodes. In stress environments taller plants may be selected as long as the plants do not have greater internode length or more lodging.

Because of the strong association between biological yield and seed yield, plant breeders should be careful to avoid selecting large-seeded interdeterminate lines having later maturity. Wallace (13) noted than early maturity was associated with greater seed yield when rates of dry matter and seed weight accumulation and harvest indexes were high.

Compared with other grain legumes (9), the harvest indexes of the indeterminate lines were high ranging from 0.59 to 0.66 at Fortuna to 0.64 to 0.70 at Constanza (table 2). Since biological yield is related to later maturity and harvest indexes are already high, the best approach for selecting for greater yield within a specific range of maturity may be to select for greater seed yield production per day.

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