Inheritance of heat tolerance in common bean of Andean origin[1]

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ABSTRACT

Bean (*Phaseolus vulgaris* L.) cultivars for the Caribbean need greater heat tolerance. The principal objective of this research was to study the inheritance of heat tolerance in an Andean population. Field experiments were conducted over a two-year period (1999-2000) to test the performance of 81 bean lines derived from the cross 'DOR 303/Indeterminate Jamaica Red'. During the summer months, PR9919-116 and PR9919-168 produced significantly greater seed yields than the heat tolerant parent 'Indeterminate Jamaica Red'. Near narrow sense heritability estimates for seed yield per plant, number of pods per plant and number of seed per pod were low to intermediate, ranging from 0.16 to 0.62, thus suggesting that screening for tolerance to higher temperatures should be conducted by using advanced generation lines in replicated trials. Additive genetic correlations between seed yield per plant and number of pods per plant, number of seed per pod, and hundred seed weight were positive and significant. There were also positive and significant additive genetic correlations between hundred seed weight and number of pods per plant. Given the large additive genetic correlations between hundred seed weight and seed yield per plant and the high narrow sense heritabilities for hundred seed weight, indirect selection for larger seed size could have been used to select for heat tolerance. The line PR9920-13 had the highest mean seed yield in the winter plantings and the third greatest mean seed yield in the summer plantings. However, the performance of the other lines in the trials suggests that selection for seed yield in the winter months would not guarantee the identification of high-yielding lines for the summer months. Selection for adaptation to high temperature environments requires the evaluation of bean lines during the summer months. Mean percentage pollen viability of the lines most tolerant to heat was significantly greater than pollen viability of the heat sensitive lines. Only one breeding line, PR9920-171, combined the heat tolerance of Indeterminate Jamaica Red and the resistance to bean golden yellow mosaic virus of DOR 303.

Key words: *Phaseolus vulgaris*, heritability, additive genetic correlations, abiotic stress, bean golden yellow mosaic

RESUMEN

Herencia de la tolerancia al calor de la habichuela de origen Andino

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Los cultivares de habichuela (*Phaseolus vulgaris* L.) para el Caribe necesitan un mayor nivel de tolerancia al calor. El objetivo principal de esta investigación fue estudiar la herencia de tolerancia al calor de una población Andina. Se realizaron experimentos de campo durante un período de dos años para evaluar el comportamiento de 81 líneas del cruzamiento 'DOR 303/Indeterminate Jamaica Red'. Durante el verano, PR9919-116 y PR9919-168 produjeron rendimientos de semilla significativamente mayor que 'Indeterminate Jamaica Red', el progenitor con tolerancia al calor. Las heridabilidades en el sentido estrecho para rendimiento de semilla por planta, número de vainas por planta y número de semilla por vaina fue de baja a intermedia en magnitud, con un rango de 0.16 hasta 0.62. Estos valores de heridabilidad sugieren que la evaluación para la tolerancia al calor debe realizarse utilizando líneas avanzadas en ensayos con repeticiones. Las correlaciones genéticas aditivas entre el rendimiento de semilla por planta y el número de vainas por planta y el peso de 100 semillas fueron positivas y significativas. Además, las correlaciones entre el peso de 100 semillas y el número de vainas por planta fueron significativas y positivas. Debido a las altas correlaciones genéticas aditivas entre el peso de 100 semillas y el rendimiento de semilla por planta y las altas heridabilidades en el sentido estrecho para el peso de 100 semillas, la selección indirecta para mayor tamaño de semilla podría ser utilizada para seleccionar para tolerancia al calor. La línea PR9920-13 produjo el mayor rendimiento promedio en el invierno y fue la tercera en rendimiento promedio en las siembras del verano. Sin embargo, el comportamiento de las otras líneas en los ensayos sugiere que la selección para rendimiento de semilla en el invierno no garantiza la identificación de líneas de habichuela con alto rendimiento en el verano. La selección para adaptación a ambientes de alta temperatura requiere la evaluación de líneas de habichuela durante el verano. Los promedios de porcentaje de viabilidad de polen de las líneas tolerantes al calor fueron significativamente mayores que los promedios de las líneas sensitivas a alta temperatura. Solamente una línea, PR9920-171 combinó la tolerancia de calor de Indeterminate Jamaica Red con la resistencia al mosaico dorado amarillo de DOR 303.

INTRODUCTION

Bean (*Phaseolus vulgaris* L.) cultivars in Puerto Rico need to be adapted to a wide range of planting dates in order to supply the local market with green-shelled beans. During the summer months, high temperature can reduce bean yields. Moreover, heat may become a more limiting factor during traditional growing seasons if global temperature continues to rise (Easterling et al., 1997). Plant breeders have been successful developing small red cultivars for Central America with greater levels of heat tolerance (Rosas et al., 2000). There is a need, however, to develop Andean bean cultivars for the Caribbean with more heat tolerance (Beaver and Molina, 1997). The mottled light red kidney landrace 'Indeterminate Jamaica Red' has exhibited heat tolerance in field trials planted in Puerto Rico during the hot and humid summer months (Baiges et al., 1996). Because the incidence of bean golden yellow mosaic (BGYM) in Puerto Rico is often greater during the hot and humid summer months, Andean bean cultivars should ideally have both heat tolerance and resistance to this viral disease. DOR 303 is a mottled light red kidney breeding line from the Centro Internacional de Agricultura Tropical (CIAT) that has the *bgm-1* gene for resistance to BGYM (Vélez et al., 1998). The primary objective of this research was to study the inheritance of heat tolerance in an Andean population in order to identify an efficient selection strategy. A secondary objective was to identify a mottled light kidney breeding line that had both heat tolerance and resistance to BGYM.

MATERIALS AND METHODS

Field experiments were planted at the Substation of the University of Puerto Rico, Agricultural Experiment Station (AES) in Isabela, Puerto Rico. The planting dates for the high-temperature environments were 24 May 1999 and 15 May 2000 and the planting dates for the cooler environments were 20 December 1999 and 24 January 2000. Granular fertilizer at a rate of 50 kg/ha of N, P and K was applied shortly after planting. Weeds were controlled manually and supplemental irrigation was used to avoid water stress. Disease and pest control followed AES recommendations (Beaver et al., 1992).

A randomized complete block design with six replications was used. Eighty-one randomly derived F_8/F_9 lines from the cross 'DOR 303/Indeterminate Jamaica Red' and the parents were evaluated in the field experiments. Indeterminate Jamaica Red is a mottled light red kidney bean landrace that has exhibited heat tolerance in Puerto Rico and the U.S. (Baiges et al., 1996; Miklas et al., 2000). DOR 303 is a mottled light red kidney bean line from CIAT that has the *bgm-2* gene for resistance to bean golden yellow mosaic (Vélez et al., 1998) but is sensitive to high temperature. Experimental units were single 1.0-m rows with a spacing of 0.6 m between rows and a within-row spacing of approximately 0.1 m. Analyses of variance were conducted and means of lines were compared by using Least Significant Differences ($P < 0.05$).

At harvest maturity, a random sample of four plants was taken from each experimental unit. The number of pods, number of seed and seed weight from the four-plant sample were used to calculate number of pods per plant, number of seed per pod and seed yield per plant. A random sample of 100 seed was used to estimate individual seed weight. Seed yield (kg/ha) was estimated using seed weights from the experimental units.

Near narrow sense heritabilities for the 1999 and 2000 summer plantings were based on variance component estimates on a progeny mean basis by the following formula:

$$\text{Narrow sense heritability} = h^2_{NS} = \sigma^2_A/\sigma^2_P$$

$$\text{Additive genetic variance for } F_8 \text{ lines} = \sigma^2_A = \sigma^2_{(\text{Among F8 lines})}/(1.984)$$

$$\text{Phenotypic variance} = \sigma^2_P = [\sigma^2_{A\,+}\,(\sigma^2_E/r)]$$

where σ^2_E = error mean square, and r = number of replications. Standard errors of variance component heritability estimates were calculated as described by Hallauer and Miranda (1988).
The additive genetic correlations were calculated as follows:

$$r = \Sigma L_1L_2/(\sigma^2_{L1*}\sigma^2_{L2})^{1/2}$$

where σ^2_{L1} and σ^2_{L2} are the additive genetic variances of the dependent variables to be correlated and ΣL_1L_2 is the sum of crossproducts of the variables. The significance of the additive genetic correlations was tested by using t tests ($P < 0.05$).

On the basis of seed yields from the summer 1999 planting, five of the most heat-tolerant lines and five of the most heat-sensitive lines were selected. These lines and the parents were used during the summer of 2000 to measure pollen viability. Samples of 500 pollen grains were taken from five recently opened flowers of each line and placed on a slide. The samples were washed with 50% ethanol to eliminate oils on the surface of the pollen grains. The pollen received two drops of methyl green-phloxine before a slide cover was placed on the sample. Each sample was placed in a petri dish for at least three minutes to prevent desiccation and to permit the dye to react with the pollen grains. A microscope with a magnification of 100-125× was used to observe pollen viability, which was expressed as a percentage. Viable pollen grains were swollen with red cytoplasm and blue-green cell walls. Non-viable pollen grains were mostly blue-green with, at times, some red residue in the cytoplasm (Weaver et al., 1985).

Heat tolerant bean lines were evaluated at the University of Puerto Rico for reaction to bean golden yellow mosaic virus. A greenhouse screening technique was used to inoculate the plants with viruliferous whiteflies (Adames-Mora et al., 1996). Approximately 20 days after inoculation, lines that had not developed BGYM symptoms were classified as resistant.

RESULTS AND DISCUSSION

Maximum mean temperatures at the Isabela Substation during the months of June, July and August of 1999 and 2000 were greater than 30° C and mean minimum temperatures were greater than 21° C. Maximum temperatures during the months of January, February and March of 2000 and 2002 averaged 27.9° C and mean minimum temperature was 19.1° C. This small difference in maximum and minimum temperatures is sufficient to cause heat stress when beans are planted on the coastal plains of Puerto Rico during the summer months.

During the summer months, PR9919-116 and PR9919-168 had mean seed yields significantly greater than that of the heat tolerant parent Indeterminate Jamaica Red (Table 1). The three highest-yielding lines were ranked no lower that fifth in 1999 and 2000, whereas the mean yield of the heat-sensitive parent DOR303 was less than 500 kg/ ha. The heat-tolerant lines were able to produce greater seed yield than DOR 303 by producing a greater number of seed per pod and a greater individual seed weight (Table 2). In 1999, the heat tolerant lines also produced a greater number of pods per plant than DOR 303. In a greenhouse study of heat tolerance, Baiges et al. (1996) observed that Indeterminate Jamaica Red produced a greater seed yield than DOR 303 by producing a greater number of seed per pod and having a larger seed size.

Near narrow sense heritability estimates for seed yield per plant, number of pods per plant and number of seed per pod were low to intermediate, ranging from 0.16 to 0.62. These results suggest that in order to have sufficient precision to detect differences among lines, screening for tolerance to higher temperatures should be conducted by using advanced generation lines in replicated trials (Table 3). Miklas et al. (2000) conducted a greenhouse experiment in Mayagüez, Puerto Rico,

TABLE 1.—*Mean yield of the 10 most heat-tolerant lines from the cross 'DOR303/ Indeterminate Jamaica Red' when planted at the Isabela Substation during the summer months of 1999 and 2000.*

	1999		2000		
Identification	Seed yield (kg/ha)	Rank	Seed yield (kg/ha)	Rank	Combined seed yield (kg/ha)
PR9919-116	2,509	1	1,864	4	2,187
PR9919-168	1,733	2	2,013	1	1,873
PR9920-13	1,604	5	1,958	2	1,781
PR9220-36	1,553	9	1,897	3	1,725
PR9919-148	1,601	6	1,814	5	1,707
PR9919-38	1,635	3	1,715	7	1,675
PR9920-83	1,605	4	1,599	8	1,602
PR9920-171	1,427	10	1,772	6	1,600
PR9920-20	1,560	7	1,520	9	1,540
PR9920-118	1,560	8	1,487	10	1,523
IJR[1]	1,310		1,531		1,421
DOR 303	266		491		379
LSD (0.05)					375

[1] Indeterminate Jamaica Red.

TABLE 2.—*Means of yield components of the 10 most heat-tolerant lines from the cross 'DOR303/Indeterminate Jamaica Red' when planted at the Isabela Substation during the summer months of 1999 and 2000.*

	Number pods/plant		Number seed/pod		Hundred seed weight (g)	
Identification	1999	2000	1999	2000	1999	2000
PR9919-116	18.2	21.8	2.8	2.6	31	31
PR9919-168	21.6	24.5	2.7	2.5	32	29
PR9920-13	20.0	25.9	2.9	2.4	32	29
PR9220-36	21.5	22.4	3.1	2.6	32	29
PR9919-148	20.7	22.3	2.9	2.5	32	30
PR9919-38	20.5	22.4	2.7	2.7	33	29
PR9920-83	23.9	27.3	2.9	2.5	31	30
PR9920-171	24.3	22.7	2.5	2.3	26	29
PR9920-20	18.4	24.1	3.0	2.4	32	29
PR9920-118	21.8	20.5	2.8	2.9	31	29
IJR[1]	19.5	21.5	2.9	3.0	31	29
DOR 303	12.6	20.7	1.7	1.6	11	17
LSD (0.05)	4.8	7.3	0.4	0.5	4	4

[1] Indeterminate Jamaica Red.

to evaluate heat tolerance in the cross 'Red Hawk × Indeterminate Jamaica Red'. Only yield (seed weight per plant) and pod set (number of pods per plant) had significant additive genetic effects in the generation means analysis. Shonnard and Gepts (1994) evaluated two Andean populations in high temperature environments in California and found significant additive effects for flower bud formation and percentage pod fill. Dickson and Petzoldt (1989) found narrow sense heritability for pod set of snap beans under heat stress to be low (<15%).

Additive genetic correlations between seed yield per plant and number of pods per plant, number of seed per pod, and hundred seed weight were positive and significant (Table 4). There were also positive and significant additive genetic correlations between hundred seed weight and number of pods per plant. Given the large additive genetic correlations between hundred seed weight and seed yield per plant (0.92 and 0.89) and the relatively high narrow sense heritabilities for hundred

TABLE 3.—*Heritability estimates and standard errors for seed yield and seed yield components of bean lines planted during the summer months.*

Year	Seed yield/plant (g)	Number pods/plant	Number seed/pod	Hundred seed weight (g)
1999	0.62 ± 0.26	0.28 ± 0.21	0.54 ± 0.24	0.85 ± 0.29
2000	0.24 ± 0.24	0.35 ± 0.22	0.16 ± 0.19	0.68 ± 0.26

TABLE 4.—*Additive genetic correlations between yield components of bean lines planted during the summer months.*

	Number pods/plant		Number seed/pod		Hundred seed weight (g)	
	1999	2000	1999	2000	1999	2000
Number seed/pod	0.21	-0.59*				
Hundred seed weight (g)	0.46*	-0.09	0.71*	0.91*		
Seed yield/plant (g)	0.67*	0.41*	0.76*	0.61*	0.92*	0.89*

*Significant at $P < 0.05$.

seed weight (0.85 and 0.68), indirect selection for larger seed size could have been used to select for greater seed yield in higher temperature environments.

Mean seed yields of Indeterminate Jamaica Red in the winter months were double and seed yields of DOR 303 were 4× greater than seed yields in the summer months. PR9920-13 had the highest seed yield in the winter plantings and the third greatest seed yield in the summer plantings (Tables 1 and 5). However, the performance of the other lines in the trials suggests that selection for seed yield in the winter months would not guarantee the identification of high-yielding lines for the summer months. Selection for adaptation to high temper-

TABLE 5.—*Mean yield of the 10 highest-yielding lines from cross 'DOR303/ Indeterminate Jamaica Red' when planted at the Isabela Substation during the winter months of 1999 and 2002.*

	1999		2002		
Identification	Seed yield (kg/ha)	Rank	Seed yield (kg/ha)	Rank	Combined seed yield (kg/ha)
PR9920-13	1,822	10	4,039	1	2,930
PR9920-117	2,303	3	3,448	6	2,876
PR9919-172	2,361	1	3,382	9	2,871
PR9920-48	2,113	8	3,612	3	2,862
PR9919-58	2,295	4	3,426	7	2,860
PR9920-47	1,891	9	3,763	2	2,827
PR9920-109	2,148	6	3,500	4	2,823
PR9919-61	2,143	7	3,485	5	2,814
PR9919-124	2,306	2	3,294	10	2,800
PR9920-148	2,194	5	3,393	8	2,793
IJR[1]	2,334		3,327		2,831
DOR 303	1,210		1,997		1,603
LSD (0.05)					451

[1] Indeterminate Jamaica Red.

ature environments requires the evaluation of bean lines during the summer months. In comparison with the highest-yielding lines in the winter months, there was less change in rank between years among the heat tolerant lines (Table 1), all of which suggests that high temperature may have been the most important seed yield constraint during the summer months.

Mean percentage pollen viability of the most heat tolerant lines was significantly greater than that of the heat sensitive lines (Table 6). Similar differences in percentage pollen viability were observed between the heat tolerant parent Indeterminate Jamaica Red and DOR303. Weaver et al. (1985) used staining to demonstrate that common bean pollen was sensitive to high temperature. In addition to reduced pollen viability, Porch and Jahn (2001) found heat-sensitive bean lines to have indehiscent anthers containing abnormal pollen. Dickson and Petzoldt (1989) also found that heat stress near anthesis reduced pod and seed set of snap beans.

Only one breeding line, PR9920-171, combined the heat tolerance of Indeterminate Jamaica Red and the bean golden yellow mosaic virus resistance of DOR 303. PR9920-171 ranked 10th and 6th in seed yield in the high temperature environments (Table 1). In the cooler environments, seed yields of PR9920-171 averaged 1,922 kg/ha in 2000 and 3,068 kg/ha in 2002. During the summer of 2000, the mean percentage pollen viability of PR9920-171 was 91.5%. Greenhouse evaluations conducted at the University of Puerto Rico Mayagüez Campus found PR9920-171 to have a bean golden yellow mosaic reaction similar to that of DOR303.

TABLE 6.—*Mean percentage pollen viability of F_8 lines from the cross 'DOR303/Indeterminate Jamaica Red' planted at the Isabela Substation in June, 2000.*

Five highest yielding lines at the Isabela Substation in the June 1999 planting		Five lowest yielding lines at the Isabela Substation in the June 1999 planting	
Identification	Pollen viability (%)	Identification	Pollen viability (%)
PR9920-13	88.4	PR9919-74	71.9
PR 9919-168	88.3	PR9920-3	70.9
PR9920-83	86.8	PR9920-25	67.5
PR9919-148	83.1	PR9920-7	67.3
PR9919-38	78.4	PR9920-34	65.6
Mean	85.0	Mean	68.6
Ind. Jamaica Red	93.7	DOR303	67.4
LSD (0.05)	10.6		
CV (%)	8.0		

LITERATURE CITED

Adames-Mora, C., J. S. Beaver and O. Díaz, 1996. Una metodología para evaluar en el invernadero el virus del mosaico dorado de la habichuela. *J. Agric. Univ. P.R.* 80:65-72.

Baiges, S., J. S. Beaver, P. N. Miklas and J. C. Rosas, 1996. Evaluation and selection of dry beans for heat tolerance. Ann. Rep. Bean Improv. Coop. 39:88-89.

Beaver, J. S. and A. Molina C., 1997. Mejoramiento de frijol para el Caribe. pp. 353-376. *In:* S. P. Singh y O. Voysest (eds.) 1977. Taller de mejoramiento de frijol para el Siglo XXI: Bases para una estrategia para América Latina. 559 pp. CIAT, Cali, Colombia.

Beaver, J. S., R. Echávez-Badel, A. Armstrong and E. Schröder, 1992. Conjunto tecnológico para la producción de habichuela. Estación Experimental Agrícola. Universidad de Puerto Rico, Mayagüez, PR. 29 pp.

Dickson, M. H. and R. Petzoldt, 1989. Heat tolerance and pod set in green beans. *J. Amer. Soc. Hort. Sci.* 114:833-836.

Easterling, D. R., B. Horton and P. D. Jones, 1997. Maximum and minimum temperature trends for the globe. *Science* 277:364-367.

Hallauer, A. R. and J. B. Miranda, 1988. Quantitative genetics in maize breeding. 2nd ed. Iowa State Univ. Press. Ames.

Miklas, P. N., R. Hannan, J. R. Smith, J. S. Beaver, R. Riley and A. Antonius, 2000. Transferring heat tolerance and indeterminancy from Indeterminate Jamaica Red (PI 163122) to kidney bean. Ann. Rep. of the Bean Improv. Coop. 43:68-69.

Porch, T. G. and M. Jahn, 2001. Effects of high-temperature stress on microsporogenesis in heat-sensitive and heat-tolerant genotypes of *Phaseolus vulgaris*. *Plant, Cell and Environment* 24:723-731.

Rosas, J. C., A. Castro, J. S. Beaver, C. A. Pérez, A. Morales and R. Lepiz, 2000. Mejoramiento genético para tolerancia a altas temperaturas y resistencia a mosaico dorado en frijol común. *Agronomía Mesoamericana* 11(1):1-10.

Shonnard G. C. and P. Gepts, 1994. Genetics of heat tolerance during reproductive development in common bean. *Crop Sci.* 34:1168-1175.

Vélez, J. J., M.J. Bassett, J. S. Beaver and A. Molina, 1998. Inheritance of resistance to bean golden mosaic virus in common bean. *J. Amer. Soc. Hort. Sci.* 123:628-631.

Weaver, M. L., H. Timm, M. J. Silbernagel and D. W. Burke, 1985. Pollen staining and high temperature tolerance of bean. *J. Amer. Soc. Hort. Sci.* 110:797-799.

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