DROUGHT RESISTANCE OF TROPICAL DRY BLACK BEAN LINES AND CULTIVARS

[RESISTENCIA A SEQUÍA DE LINEAS Y VARIEDADES DE FRIJOL NEGRO TROPICAL]

Ernesto López-Salinas[1], Oscar H. Tosquy-Valle[1], Jorge A. Acosta-Gallegos[2*], Bernardo Villar-Sánchez[3] and Francisco J. Ugalde-Acosta[1]

[1] Campo Experimental Cotaxtla. CIRGOC. INIFAP. Km 34 Carr. Veracruz-Córdoba. Apdo. Postal 429, 91700, Veracruz, Ver., México;
[2] Campo Experimental Bajío.CIRCE. INIFAP. km 6.5 Carr. Celaya-San Miguel de Allende. Apdo. Postal 112, 38000, Celaya, Gto., México. . E- mail: jamk@prodigy.net.mx;
[3] Campo Experimental Centro de Chiapas. CIRPAS. INIFAP. Km 3.0 Carr. Ocozocoautla-Cintalapa. C. P. 29140, Ocozocuautla, Chis., México.
**Corresponding Author*

SUMMARY

The objectives of this research were to classify black seeded dry bean genotypes for their drought tolerance and to identify those with the highest seed yield efficiency under irrigated and drought stressed conditions. During the 2008 Winter-Spring growing season two experiments were carried out at Medellín de Bravo, Veracruz; one was irrigated during the whole growing cycle, whereas in the other one, irrigation was withheld from the onset of flowering. Nine lines, six improved cultivars and the 'Arbolito' landrace (local control) were evaluated using a randomized complete block design with three replications. Data recorded included days to physiological maturity, seedless aerial dry biomass production, number of pods per plant, weight of 100 seeds and seed yield. Analysis of variance for the irrigated and drought stressed conditions, as well as combined analysis were performed. The drought susceptibility index (DSI) and the relative efficiency index (REI) were used as efficiency criteria. Under irrigated conditions, Negro INIFAP, 82L-17-18, Negro Tacaná and Negro Veracruz were the most productive genotypes with more than 1.0 t ha^{-1}. Under drought conditions, the last two genotypes along with line DOR 448 were the most productive with a seed yield higher than 400 kg ha^{-1}. On average, the yield obtained under drought conditions was 37.7% of that under irrigation. With DSI values of 0.71, 0.85 and 0.87, lines DOR-448, NGO 17-99 and Icta Ju-97-1, respectively, were considered as drought tolerant. Under both moisture conditions, Negro Tacaná and Negro Veracruz with REI values of 1.67 and 1.47, respectively, showed the highest seed yield efficiency.

Key words: *Phaseolus vulgaris* L.; moisture stress; genetic resistance; selection; yield.

RESUMEN

Los objetivos de esta investigación fueron: clasificar genotipos de frijol negro por su tolerancia a sequía e identificar los de mayor eficiencia en el rendimiento en condiciones de riego y sequía. Para ello, en invierno-primavera 2008 se condujeron dos experimentos en Medellín de Bravo, Veracruz; uno con riego todo el ciclo y el otro sin riego, a partir del inicio de floración. Se evaluaron nueve líneas, seis variedades y Criollo Arbolito (testigo local) en diseño bloques completos al azar con tres repeticiones. Se cuantificó días a madurez fisiológica, producción de materia seca sin grano, vainas por planta, peso de 100 semillas y rendimiento de grano. Se hicieron análisis de varianza por condición de humedad y uno combinado. Como estimadores de eficiencia se utilizaron el índice de susceptibilidad a sequía (ISS) y el índice de eficiencia relativa del rendimiento (IER). Con riego, Negro INIFAP, 82L-17-80, Negro Tacaná y Negro Veracruz, fueron los genotipos más productivos con más de 1,0 t ha^{-1}. Con sequía sobresalieron los dos últimos genotipos, más la línea DOR 448, con rendimientos superiores a 400 kg ha^{-1}. El rendimiento bajo sequía en promedio representó el 37,7% con respecto al de riego. Con ISS de 0,71, 0,85 y 0,87, las líneas DOR-448, NGO 17-99 e Icta Ju-97-1, respectivamente, fueron clasificadas como resistentes a sequía. Las variedades Negro Tacaná y Negro Veracruz con valores de IER de 1,67 y 1,47, mostraron la mayor eficiencia en el rendimiento en ambas condiciones de humedad.

Palabras clave: *Phaseolus vulgaris* L.; estrés de humedad; resistencia genética; selección; rendimiento.

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INTRODUCTION

In the southeast humid tropical region of Mexico, dry bean is mostly grown under rainfall and residual moisture conditions. Main producing states are Chiapas, Oaxaca and Veracruz, in which during 2007 107,352 t of dry bean were produced in 209,898 ha with an average yield of 648 kg ha^{-1} (SAGARPA, 2008).

That low seed yield is mostly due to a period of drought stress that hits the rainfed crop (132,393 ha) from July 20 to August 20, and to terminal drought stress that hits the crop when grown under residual moisture conditions (70,822 ha) (Lopez *et al*., 2002). In both cases seed yield is low due to moisture deficiencies during the reproductive and seed filling growth phases, that causes low seed set per pod, low number and short pods per plant (Yánez-Jiménez and Kohashi-Shibata, 1987; Nielsen and Nelson, 1998), and depending on the duration of the drought period and its magnitude, it can cause yield losses from 20 to 100% in commercial bean fields (López *et al*., 2008).

The development of drought resistant cultivars is a viable alternative to increase dry bean seed yield under drought stressed conditions (Frahm *et al.*, 2003). The use of selection indexes with dry bean genotypes grown under irrigated and stressed conditions from the flowering stage onwards, is a useful tool in the breeding of dry bean against this abiotic constraint (Schneider *et al*., 1997). It has been suggested that the selection of dry bean genotypes must be based on the combination of criteria related to seed yield under both moisture conditions (relative yield efficiency index or geometric mean), as well as those that include the reduction in seed yield from the irrigated to the drought stressed condition (drought susceptibility index) (Fisher and Maurer, 1978).

In recent studies on the evaluation for drought resistance in black seeded dry bean genotypes carried out in central Veracruz, line NGO 17-99 and cultivar Negro INIFAP resulted highly efficient in average seed yield under irrigated and drought stressed conditions (López *et al*., 2008). In the present irrigated-drought stressed study, these two genotypes along with other 14 were evaluated with the aim of classifying their reaction under drought stress, as well as to identify those of higher seed yield efficiency under both moisture conditions.

MATERIAL AND METHODS

Two trials were established during the winter-spring cycle of 2008 at the Cotaxtla Experimental Station, Medellin de Bravo county, state of Veracruz, located at 18º 50' Northern latitude, 96º 10' West longitude, and at 15 masl. The climate in this location is hot and subhumid [Aw (w)(g)], that corresponds to the less humid of the hot and sub humid (Garcia, 1987), with an annual average maximum temperature of 25.4°C and a minimum of 7.0°C and a yearly rainfall of 1,336.8 mm (Díaz *et al*., 2006). The soil in the experimental site is a clay-loam, with pH 6.4, medium OM content (2.14%), nitrogen (0.11%) and potassium (160 ppm) and is extremely rich in P content with 37.3 ppm (López-Collado, 1998).

In both trials 16 black seeded dry bean genotypes were evaluated, Mesoamerica race (Singh *et al*., 1991): lines ICTA Ju-97-1, DOR-667, and DOR-448 were introduced from the International Center for Tropical Agriculture (CIAT); lines NGO 99038, NGO 99055 and NGO 99176 from the bean program at the Bajio Experimental Station (CEBAJ) of INIFAP at Celaya, Guanajuato, Mexico; NGO 17-99, ELS-15-55 and 82L-17-80 from the bean program at Cotaxtla Experimental Station (CECOT) of INIFAP at Veracruz, Ver., México and the commercial cultivars Negro Papaloapan, Negro Tacaná, Negro INIFAP, Negro Veracruz, Negro Huasteco 81, Negro Jamapa and the Arbolito landrace (local check). For planting a random complete block design with three replications was used, plots were 3 row 5.0 m in length and 0.75 m row width; at harvest the central row was used for determinations.

Sowing date was on February 13th with a plant stand of 250,000 plants ha^{-1}. One of the trials was conducted under irrigation during the whole crop cycle, for that irrigation was applied before sowing to allow for a uniform germination, afterwards six irrigations were applied at intervals from 9 to 12 days, in agreement with the availability of soil moisture; the total water applied was of 350 mm (50 mm per irrigation). In the second trial only four irrigations were applied, that accounted for 200 mm; last irrigation was applied at 41 days after planning, when most genotypes were at the onset of flowering, a critical drought susceptible stage (Acosta *et al.*, 1999). Under this condition, the bean plants did not get any irrigation for 34 days until an unusual rainfall of 68 mm occurred on April 28, when the plants were reaching physiological maturity. In both moisture conditions, pest control and harvest was done following the suggestions of Ugalde *et al*. (2004).

During crop development the following traits were recorded: 1) number of days to physiological maturity, counted after sowing until a genotype show 50 % of its pods changed from green to yellow or purple color; 2) above ground dry matter without seed, determined from the weight of the plants harvested per plot and expressed as kg ha^{-1}; 3) seed yield, measured per plot and expressed as kg ha^{-1} at 14% moisture; 4) number of pods per plant, calculated as the average from five plants taken at random during harvest, and 5) 100-seed weight in g from each plot.

For seed yield individual analyses of variance were done per moisture treatment and one combined, this with the aid of the statistical package from the Universidad Autónoma de Nuevo León, version 2.5 (Olivares, 1994). On those traits that show significant differences, means were separated by Duncan's test at a $p \leq 0.05$.

In order to calculate the effect of drought on the seed yield of each genotype, the method of Fisher and Maurer (1978) was utilized. In addition, the relative efficiency index proposed by Graham (1984) for genotype classification was calculated by considering the seed yield under both moisture conditions.

The drought susceptibility index was calculated with the equation: : DSIi = 1-(Yi_i/Yc_i)/DII, where Yi = average yield of ech genotype under drought stress; Yc = average yield of each genotype under irrigated conditions during the whole crop cycle; the drought intensity index (DII) was obtained with the equation DII = 1-(Yi/Yc), in which Yi = average yield of ech genotype under drought stress; Yc = average yield of each genotype under irrigated conditions during the whole crop cycle. This index corresponds to the seed yield lost due to drought; when the lost is small, the DII score is low. A 1.0 average indicates an average drought susceptibility; a value larger than 1.0 indicates that the genotype is susceptible and values near zero indicates higher drought resistance (Fischer y Maurer, 1978).

The relative efficiency index (REI) was calculated with the equation: REIi = (Yi_i / Yi) (Yc_i / Yc), where REIi = the relative efficiency index of each genotype; Yi_i = seed yield of genotype i under drought stress; Yi average yield from all genotypes under drought stress; $Yc_{i\ =}$ seed yield of genotype i under irrigation during the whole crop cycle; and Yc = the average yield under irrigation during the whole growth cycle.

RESULTS AND DISCUSSION

Under irrigated conditions significant differences were observed among bean genotypes for all traits recorded, with the exception of 100-seed weight. In the drought stressed treatment significant differences were observed ($p \leq 0.05$) for the number of pods per plant, 100-seed weight and for seed yield. These results indicate that under drought conditions, the seed yield and components were differentially affected among the genotypes.

Under irrigated conditions 11 genotypes showed a longer growth cycle; NGO 99055, DOR 667 and NGO 99038 were the most late to reach maturity with 90 d (Table 1). Under drought conditions all genotypes showed a similar number of days to reach physiological maturity. In general, under drought conditions the number of days to physiological maturity is reduced (Rosales-Serna *et al.*, 2000; Terán and Singh, 2002a; 2002b). In this study the reduction in the growth cycle due to drought strees varied from 10.39 to 11.54% (Table 1). Under irrigation six genotypes resulted superior in above ground dry matter production, cultivar Negro INIFAP and line NGO 99038 displayed the highest yield. However, these genotypes showed the larger decrease due to drought stress, whereas the cultivar Negro Jamapa and lines DOR-448 and NGO 99055 were the least affected (Table 1). In general, the genotypes of larger biomass production, under irrigation as well as under drought stress, display high seed yield at each moisture condition (Rosales-Serna *et al.*, 2000; Acosta-Díaz *et al.*, 2004).

Negro Huasteco 81, Icta Ju-97-1, Negro INIFAP and Negro Veracruz under irrigated conditions displayed the highest production of pods per plant. However, only the last two genotypes were outstanding on the production of pods per plant under drought strees; the former two were largely affected by the applied drought strees (reduction of 72.54 and 75.16%, respectively), with a reduction larger than the average (Table 2). The average number of pods per plant was superior under irrigation as compared to the water strees treatment; this confirms the report by Nielsen and Nelson (1998), whom observed a reduction in the number of pods in plants submitted to drought strees at the flowering stage; that effect could have being due to ovule or pollen damage (Kokubun *et al.*, 2001) and to a competition for assimilates among pods established sequentially, being in general, the first pods that set the ones that are retained by the plant.

Under drought stress conditions, eight genotypes showed a higher 100-seed weight, significantly superior to the other genotypes, in this group lines 82L-17-80 and ELS-15-55 were less affected by the stress with a reduction lower than 13% (Table 2). The average decrease in seed weight caused by the drought stress was around 20%, lower than the one exhibited by the number of pods per plant, this is due to the fact that the plants under stress have lower capacity to translocate assimilates towards the seed (Rao, 2001).

Table 1. Effect of two moisture conditions upon physiological maturity and production of above ground dry matter of dry bean genotypes. Medellín de Bravo, Veracruz, Mexico. Winter-Spring season 2008.

Genotype	Physiological maturity (d)			Dry matter without seed (kg ha^{-1})		
	Irrigated	Stressed	Reduction (%)	Irrigated	Stressed	Reduction (%)
Icta Ju-97-1	86.67 *	76.67	11.54	1627	969	40.44
ELS-15-55	88.33 *	78.33	11.32	1795 *	1031	42.56
NGO 17-99	85.00	75.67	10.98	1552	1085	30.09
N INIFAP	83.33	74.67	10.39	1965 *	1049	46.62
NGO 99176	88.33 *	78.33	11.32	1440	915	36.46
NGO 99055	90.00 *	80.00	11.11	1289	1022	20.71
DOR-667	90.00 *	80.00	11.11	1751 *	969	44.66
DOR-448	86.67 *	76.67	11.54	1218	978	19.71
N Tacaná	85.00	75.67	10.98	1787 *	1182	33.86
N Veracruz	85.00	75.67	10.98	1475	1013	31.32
NGO 99038	90.00 *	80.00	11.11	1893 *	1031	45.54
N Papaloapan	88.33 *	78.33	11.32	1440	987	31.46
N Jamapa	88.33 *	78.33	11.32	1351	1138	15.77
N Huast.81	86.67 *	76.67	11.54	1707 *	1085	36.44
82L-17-80	83.33	74.67	10.39	1573	1005	36.11
C Arbolito	86.67 *	77.33	10.78	1458	960	34.16
Promedio	86.98	77.31	11.12	1582	1026	35.15
ANVA	S	NS		AS	NS	
CV (%)	2.90	3.07		11.34	11.78	
LSD (0,05)	4.20			299.25		

S = Significative effect. NS = Non significative effect. HS = Highly significative effect.
* Significantly superior genotypes according to the LSD test (0,05).

Table 2. Effect of two moisture conditions on the number of pods per plant and 100-seed weight of 16 dry bean genotypes. Medellín de Bravo, Veracruz, Mexico. Winter-Spring season 2008.

Genotype	Number of pods per plant			100-seeds weight (g)		
	Irrigated	Stressed	Reduction (%)	Irrigated	Stressed	Reduction (%)
Icta Ju-97-1	17.43 *	4.33	75.16	23.33	15.33	34.29
ELS-15-55	14.30	7.23 *	49.44	20.67	18.00 *	12.99
NGO 17-99	8.77	8.87 *	-1.14	23.33	18.67 *	19.98
N INIFAP	14.90 *	7.10 *	52.35	21.33	16.00	24.99
NGO 99176	13.33	8.43 *	36.76	24.00	18.67 *	22.21
NGO 99055	6.43	4.53	29.55	20.67	17.33	16.16
DOR-667	9.03	7.57 *	16.17	22.00	17.33	21.23
DOR-448	13.33	8.67 *	34.96	23.33	20.00 *	14.27
N Tacaná	12.87	5.97 *	53.61	23.33	16.67	28.55
N Veracruz	14.70 *	7.43 *	49.46	22.00	16.67	24.23
NGO 99038	11.90	5.43	54.39	21.33	17.33	18.75
N Papaloapan	7.23	7.90 *	- 9.27	22.67	19.33 *	14.73
N Jamapa	10.80	4.80	55.56	22.67	19.33 *	14.73
N Huast.81	19.77 *	5.43	72.54	23.33	18.67 *	19.98
82L-17-80	12.00	4.67	61.08	22.00	19.33 *	12.14
C Arbolito	11.33	4.67	58.78	21.33	16.67	21.85
Promedio	12.38	6.44	47.98	22.33	17.83	20.15
ANVA	AS	S		NS	S	
CV (%)	26.20	29.23		7.66	8.69	
LSD (0.05)	5.41	3.14			2.58	

S = Significative effect. NS = Non significative effect. HS = Highly significative effect.
* Significantly superior genotypes according to the LSD test (0,05).

With a seed yield higher than 1.0 t ha^{-1}, Negro INIFAP, 82L-17-80, Negro Tacaná and Negro Veracruz, were the highest yielding genotypes under irrigated conditions; from these, Negro INIFAP and Negro Tacaná, along with line NGO 99038 produced the highest dry matter, although the last genotype had a low seed yield. Under drought conditions, cultivars Negro Tacaná and Negro Veracruz, along with the line DOR-448, had the higher seed yields (Table 3), whose dry matter production resulted similar. From the combined analysis of variance the seed yield was significantly different between environments ($p \leq 0.05$) and genotypes ($p \leq 0.01$), but not their interaction. This indicates that the genotypes had a similar order under both moisture conditions and that all were affected by the stress treatment. Under full irrigation the yield was 62.3% higher than the one under drought stress. A group of nine genotypes resulted outstanding ($p \leq 0.05$), from this group cultivars Negro Tacaná, Negro INIFAP, Negro Veracruz and line 82L-17-80 had the highest seed yield (Table 3).

Seed yield reduction due to drought effects was different among genotypes, being severe on Negro Papaloapan, Negro INIFAP, 82L-17-80 and Criollo Arbolito, genotypes that displayed largest drought susceptibility indexes (DSI). Line DOR 448 show the minimum reduction in seed yield, as well as the lowest DSI, along with lines NGO 17-99 and Icta Ju-97-1 that also displayed drought resistance (Fisher and Maurer, 1978). The use of this index to eliminate genotypes must be taken with caution and include more characteristics into consideration, since the most tolerant genotypes can not be the most productive under drought stress (Rosales-Serna *et al*., 2000), as occurred in this study since none of these three genotypes resulted outstanding in seed yield under drought stress. It is important to mention that from the R6 to R9 growth stages the crop under stress was not irrigated and none rainfall was registered, thus the drought intensity index was 0.62. Cultivars Negro Tacaná and Negro Veracruz displayed the highest indexes of relative efficiency (IER), that points out to a high average seed yield from both moisture conditions (Table 3). IER values were highly related to seed yield, similar finding were previosly reported for dry bean under drought stress (Mayek *et al*., 2003; López *et al*., 2008).

Table 3. Seed yield of 16 dry bean genotypes grown under two moisture conditions and indexes of drought susceptibility (DSI) and seed yield efficiency (REI). Medellín de Bravo, Veracruz, Mexico. Winter-Spring season 2008.

Genotype	Irrigated	Stressed	Average	Reduction (%)	DSI	REI
Icta Ju-97-1	778	356 *	567	54.2	0.87	0.92
ELS-15-55	889 *	379 *	634 *	57.4	0.92	1.12
NGO 17-99	741	348 *	544	53.0	0.85	0.86
N INIFAP	1,200 *	340 *	770 *	71.7	1.15	1.36
NGO 99176	958 *	322 *	640 *	66.4	1.06	1.03
NGO 99055	503	219	361	56.5	0.90	0.37
DOR-667	914 *	307	610 *	66.4	1.06	0.93
DOR-448	740	411 *	575	44.5	0.71	1.01
N Tacaná	1,102 *	455 *	778 *	58.7	0.94	1.67
N Veracruz	1,063 *	416 *	739 *	60.9	0.98	1.47
NGO 99038	686	228	457	66.8	1.07	0.52
N Papaloapan	853 *	231	542	72.9	1.17	0.65
N Jamapa	846 *	382 *	614 *	54.8	0.88	1.07
N Huasteco 81	996 *	393 *	694 *	60.5	0.97	1.30
82L-17-80	1,132 *	327 *	729 *	71.1	1.14	1.23
Criollo Arbolito	896 *	272	584	69.6	1.12	0.81
Promedio	893,6 *	336.6	614.9	62.3	1.0	1.0
ANVA	S	S				
CV (%)	24.06	24.04				
LSD (0.05)	358.43	134.91				

S = Significative effect. NS = Non significative effect. HS = Highly significative effect.

* Significantly superior genotypes according to the LSD test (0,05).

CONCLUSIONS

The drought stress treatment significantly affected the production of pods per plant, 100-seeds weight and seed yield per unit area. Lines DOR 448, NGO 17-99 and Icta Ju-97-1 were the most drought resistent, whereas cultivars Negro Papaloapan and Negro INIFAP and line 82L-17-80 were the most susceptible. DOR 448 also displayed low dry matter production and 100-seed weight, and NGO 17-99, along with Negro Papaloapan, were not affected in their number of pods per plant by the drought stress.

The Negro Tacaná and Negro Veracruz cultivars, showed the highest seed yield efficiency under both moisture conditions.

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