Article

Performance and adaptation of opaque black bean genotypes in environments with and without terminal drought

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Abstract

The drought at the end of the reproductive stage (terminal), is one of the main environmental factors that limit the yield of beans in the sowings of residual moisture in Veracruz and Chiapas, Mexico. The objective of this research was to determine the yield and adaptation of 13 bean genotypes under conditions of residual moisture in localities with and without terminal water stress. The new Verdín variety, together with 10 advanced lines and the Negro Tacaná and Negro Jamapa varieties were evaluated in three environments of Veracruz and Chiapas in Autumn-Winter (A-W) of 2013 and spring-summer (S-S) of 2014. The experimental design was complete random blocks with three repetitions. During the crop cycle, rainfall was recorded and the dynamics of the usable humidity of the soil was determined. The response variables were: days at physiological maturity and grain yield. Combined analyzes of the six test environments were carried out and also an analysis to determine the stability of yield and adaptation of the genotypes. The dynamics of the usable humidity indicated that, in Medellin and Ocozocoautla, in A-W of 2013 and in Medellin and Cintalapa in S-S of 2014, conditions of terminal drought prevailed, while in Tlapacoyan, in both production cycles, the plants had no stress by humidity. Thus, the differences in moisture availability during the reproductive stage, through the test locations, affected the productive response and the duration of the crop cycle of the genotypes evaluated. Among the genotypes, the Verdín variety showed high yield with and without terminal drought with 1121.7 and 1568 kg ha^{-1}, its yield was significantly (p> 0.01) higher than that of the commercial controls, Negro Tacaná and Negro Jamapa.

Keywords: *Phaseolus vulgaris*, water stress, precocity, yield.

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Introduction

In the states of Veracruz and Chiapas, the drought at the end of the crop cycle (terminal) is the environmental factor that most limits bean production in the residual moisture system of the autumn-winter and spring-summer cycles in which approximately 65 000 ha of black beans, opaque and small, of Mesoamerican breed are cultivated annually, which is the one with the highest commercial demand in southeastern Mexico (Castellanos *et al*., 1997; López *et al*., 2015).

In the residual moisture system, as the crop cycle progresses, rainfall decreases and periods of drought occur during the reproductive stage called terminal, because they coincide with the stage of grain filling, which is when the bean plants are more susceptible to the lack of moisture in the soil (Acosta-Díaz *et al*., 2004; Muñoz-Perea *et al*., 2006; López *et al*., 2011), this prevents the plant from expressing its productive potential (Núñez-Barrios *et al*., 2005; Ghassemi-Golezani and Mardfar, 2008) and depending on their duration and magnitude, can cause losses of 20 or even 100% in grain yield (Castañeda *et al*., 2006; López *et al*., 2008).

To help solve the problem indicated, from 2007 the Cotaxtla Experimental Field Bean Program of the National Institute of Forestry, Agriculture and Livestock Research (INIFAP), initiated studies on terminal drought in black beans in the center of the state of Veracruz, using the irrigation-drought methodology in combination with the use of the drought susceptibility index (ISS) (Fischer and Maurer, 1978) and the relative efficiency of yield (IER) Graham (1984), which have been effective in the identification of lines and development of improved cultivars with tolerance to this environmental factor (Rosales-Serna *et al*., 2000; Frahm *et al*., 2003).

From these research works, advanced lines and varieties were identified that presented adaptation to conditions of moisture deficiency (López *et al*., 2008; 2011), which were continued to be evaluated in Winter-Spring of 2013, along with other advanced lines of the National Bean Program of INIFAP, of the International Center for Tropical Agriculture (CIAT), in Palmira, Colombia, of the State University of Michigan, in the United States of America and the University of Puerto Rico, in Mayagüez, Puerto Rico, using the irrigation-drought methodology, and monitoring the useable moisture content in the soil during the crop cycle, to accurately determine the degree of drought in which these bean genotypes were developed (Hillel, 1980) and their productive response under conditions of stress due to humidity.

The SEN 70 line registered by the INIFAP with the name of Verdín, was selected together with another 10 lines, for its tolerance to the terminal drought and high productive efficiency under irrigation and drought (Tosquy *et al*., 2014; 2016), to conform a performance trial that was conducted during 2013 and 2014 in six environments of the states of Veracruz and Chiapas, Mexico. The objective of this research was to determine the crop cycle, yield and adaptation of 13 bean genotypes, in conditions of residual moisture, with and without terminal hydric stress, in localities of both states.

Materials and methods

The trial with the 13 genotypes was established during the autumn-winter cycle of 2013, in the localities of Ocozocoautla, in the center of the state of Chiapas, and in Medellin and Tlapacoyan, in the central and northern zones of the state of Veracruz, respectively. and in the spring-summer cycle of 2014 with sowings in February, in Medellin and Tlapacoyan, Ver. and in Cintalapa, in the center of Chiapas. In Table 1, the main environmental characteristics of the test sites of this variety are shown.

Table 1. Agricultural cycles and environmental characteristics of the evaluation sites of 13 bean genotypes in the states of Veracruz and Chiapas, Mexico.

Year	Cycle	Condition	Location/state	Altitude (m)	Texture of soil	pH edaphic	Type of weather
2013	A-W	HR	Ocozocoautla, Chiapas	805	MAA	7.20	(A)C(w_1) ig’
		HR	Medellin, Veracruz	22	Frank	6.05	Aw_0 (w)(g)
		HR	Tlapacoyan, Veracruz	92	MA	5.39	Af(m)(e)
2014	S-S	RA	Medellin, Veracruz	22	Frank	6.05	Aw_0 (w)(g)
		HR	Tlapacoyan, Veracruz	92	MA	5.78	Af(m)(e)
		RA	Cintalapa, Chiapas	595	MA	5.99	Aw''_0(w) (i’)(g)

Source: García (1987); Díaz *et al*. (2006); Serrano *et al*. (2006). A-W= Autumn-Winter; S-S= Spring-Summer; HR= residual humidity; RA= irrigation of aid during the vegetative stage of the crop; MAA= sandy clay migajón; MA= sandy loam.

The trial included six advanced black bean lines from the CIAT Bean Program [SEN-70 (Verdín), SEN-56, CIAT-103-25, SCN-2, NCB-229 and SEQ-344-21], four of the National Bean Program of INIFAP (NGO-17-99, ELS-9-27, NGO-07022 and Jamapa Plus) and the line X02-33-153 of the University of Puerto Rico, as well as the commercial varieties Negro Tacaná and Negro Jamapa (witnesses), generated for southeastern Mexico (López *et al*., 1996; Rosales *et al*., 2004). The genotypes were established in humid soil at a density of 250 000 plants ha^{-1}, in experimental design complete blocks at random with three replications and plots of three rows of 5 m in length, where the useful plot corresponded to the central furrow eliminating the last plant from its extremes.

It should be noted that in the tests conducted in spring-summer of 2014, in Medellin, Veracruz, and Cintalapa, Chiapas, three watering were applied (one in pre-sowing and two in relief during the vegetative phase of the crop) of a sheet of water of around 40 mm each, this because in both locations there were no rain events during the entire crop cycle. In the other four locations, the trial was conducted with the residual moisture of the soil and the rains that occurred during the crop cycle. The agronomic management was carried out according to the recommendations made by INIFAP, for the bean crop in the states of Veracruz and Chiapas (López *et al*., 1994; Villar *et al*., 2002).

In the experimental sites where the trial was established, the rainfall was quantified and the soil humidity in the profile was determined from 0 to 45 cm from sowing to the stage of physiological maturity of the crop. The rainfall record was made in PVC rain gauges, making the readings in graduated cylinders. Soil moisture was obtained with the gravimetric method (Florentino, 2006), in samples taken once a week, distributed at the beginning, center and end of each repetition.

Likewise, other soil samples were taken at the same depth, to determine the permanent wilting point (PMP) and the field capacity (CC) with the column method (Aguilera and Martínez, 1980); with these indicators, the soil moisture was expressed as usable humidity for the crop, 0% corresponding to the humidity of the PMP and 100% to the humidity of CC (Hillel, 1980). The values of usable soil moisture were plotted, to know their dynamics before and after the flowering of the crop. It was considered as terminal drought, when the usable moisture in the soil was less than 45% (Allen *et al*., 2006).

During the conduction of the tests the days were determined at the physiological maturity of the genotypes, counted from the sowing until the pods of 50% of plants one, changed from green to yellow or purple, and the yield of grain, which was calculated from the weight of the harvested grain of each experimental plot, in kilograms per hectare at 14% humidity. The data of both variables were subjected to a combined variance analysis of the environments in which there was drought occurrence and without terminal drought, as well as a joint analysis of the six test environments. For the separation of averages, the test was applied based on the minimum significant difference at 5% error probability (DMS, α= 0.05) (SAS Institute, 1999). An analysis of performance stability parameters was also carried out, according to the model proposed by Eberhart and Russell (1966) and the adaptation and stability of the genotypes were classified based on the regression coefficients and the regression deviations (Carballo and Márquez, 1970).

Results and discussion

Rainfall and soil moisture balance of the experimental sites

During the autumn-winter cycle of 2013 in the sites located in Ocozocoautla and Medellin, rainfall accumulated until the physiological maturity of the culture of 97.7 and 52.1 mm, respectively (Figure 1), with low humidity availability during most of the year. the reproductive phase, while in the Tlapacoyan, frequent rains were recorded, with an accumulated rainfall during the crop cycle of 391.6 mm, so that the bean plants developed without stress due to humidity.

The soils in which the trial was established showed a field capacity (CC) of 23.6, 20.3 and 13% at the sites of Medellin, Tlapacoyan and Ocozocoautla, respectively, with a permanent wilting point (PMP) of 12.5, 10.8 and 6%, in the same places, so the maximum usable humidity was 11.1, 9.5 and 7% (Hillel, 1980).

In Medellin, a gradual decrease in the available soil moisture was observed as the crop advanced to physiological maturity, which was associated with the low amount of rains that occurred during the vegetative phase. In Ocozocoautla, there was high variation in the usable humidity, especially before the flowering of the genotypes; after that period until the stage of physiological maturity, water deficit was observed, which was more severe than in Medellin, mainly due to a lower capacity of soil moisture retention (7% *vs* 9.5%), associated with its more sandy texture (52.4% *vs*

33.2% of sand) and lower content of organic matter (1.1% *vs* 2.5%). In turn, in Tlapacoyan, although the usable humidity was variable during the cultivation cycle, it remained above the critical limit (45%), so that the bean plants did not suffer from water stress throughout their development.

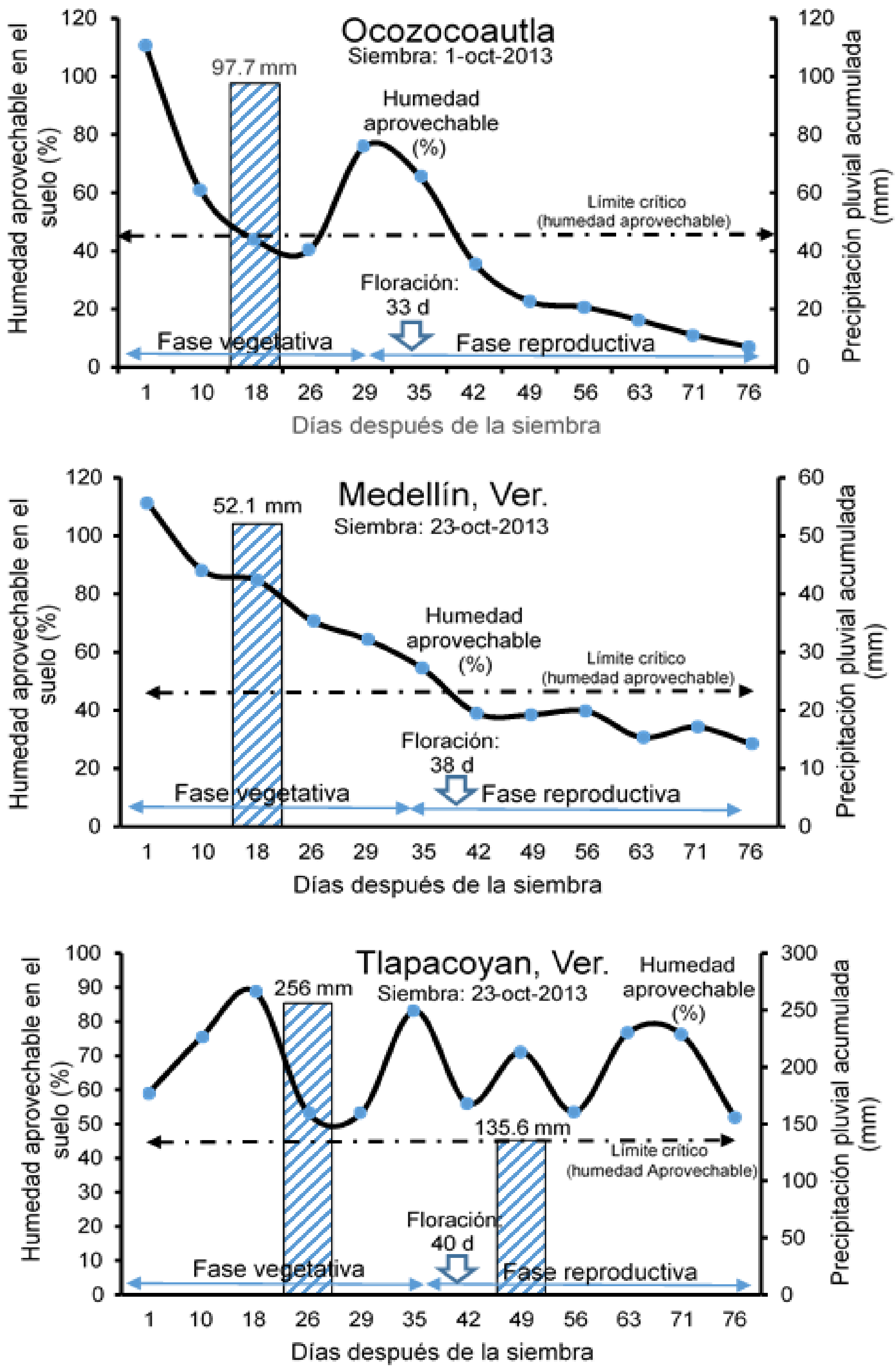

Figure 1. Rainfall occurred and available moisture in the soil profile in Ocozocoautla, Medellin and Tlapacoyan, during the autumn-winter cycle of 2013.

The usable humidity from sowing to flowering of most of the genotypes was 73.2, 67 and 61.9%, at the sites of Medellin, Tlapacoyan and Ocozocoautla, respectively. After that period, towards the final stages of the crop, the usable humidity in the respective sites was 34.3, 65.9 and 15.5%.

In the spring-summer cycle of 2014, no rainfall was recorded during the entire crop cycle at the Medellín and Cintalapa sites, so that the beans were developed with the moisture provided by the irrigation that was applied in pre-sowing and during the vegetative phase, after this phase, both sites showed a gradual decrease in the usable humidity (Figure 2), with occurrence of drought from the beginning of the pod filling stage (between 50 and 52 d after from sowing) to physiological maturity, which occurred on average at 70.7 and 68.1 d, respectively.

In turn, in Tlapacoyan rainfall was recorded that accumulated 187.2 mm during the cycle, with adequate distribution and more during the reproductive phase, so, in this case, the crop was developed under better conditions of usable humidity than in the other two test sites (mainly after flowering), which was sufficient for the bean plants to be without moisture stress until the end of the pod filling stage (69 d). Subsequently, the usable humidity decreased until exceeding the critical limit of 45% (Allen *et al*., 2006) towards the stage of physiological maturity. It is known that the occurrence of terminal drought at the end of pod filling has no effect on grain yield, because bean plants begin their maturity (Mouhouche *et al*., 1998; Nielsen and Nelson, 1998).

In the sites of Medellín, Tlapacoyan and Cintalapa the soils presented a CC of 23.6, 20.2 and 13.4% and a PMP of 12.5, 9.9 and 7.6%, respectively, which allowed a usable humidity of 11.1, 10.3 and 5.8%. The above, indicates that Cintalapa soil has less capacity to store moisture, than that of Medellin and Tlapacoyan, mainly due to its lower content of organic matter (1.36% *vs* 2.44 and 2.24%, respectively) and its more sandy texture (73.2% *vs* 66.2 and 33.2%). In the Tlapacoyan, Medellin and Cintalapa sites, the available humidity from sowing to flowering was 92.2, 90.5 and 82.4%, respectively; while, towards the terminal stage of the crop, the values in the respective sites were 66.6, 30 and 32.5%.

The usable humidity of the soil observed in the two production cycles indicate that in Medellin and in Ocozocoautla, in AW of 2013 and in Medellin and Cintalapa in SS of 2014, there were terminal drought conditions, since the usable humidity of the soil was lower to 45% during the reproductive phase of the crop (Allen *et al*., 2006), while, in Tlapacoyan, this moisture condition only prevailed from the end of the pod filling stage in spring-summer of 2014 (Figure 2), and that this did not affect the grain yield, it can be asserted that in this evaluation site, in both cycles, moisture conditions prevailed that did not cause water stress to the bean genotypes.

Physiological maturity and grain yield

Significant differences ($p \leq 0.01$) were detected between environments and genotypes, under conditions of terminal drought, without drought and in the combined analysis of the six test environments. In Tlapacoyan in the autumn-winter cycle of 2013, physiological maturity occurred on average 81 days after sowing (dds), significantly later than in the other evaluation sites (Table 2), which was due mainly to the availability of higher humidity during the crop cycle (Figure 1), which favored a longer duration of the reproductive period. In contrast, in the four environments in which there were no rains during the reproductive phase of the crop, the maturity occurred on average before 71 dds (Table 2), due to the lack of moisture after the flowering stage of the crop, which provoked an advance in physiological maturity, which according to Rosales-Serna *et al*. (2001), the acceleration of maturity occurs when the drought is prolonged during the reproductive phase and there are no favorable moisture conditions for recovery.

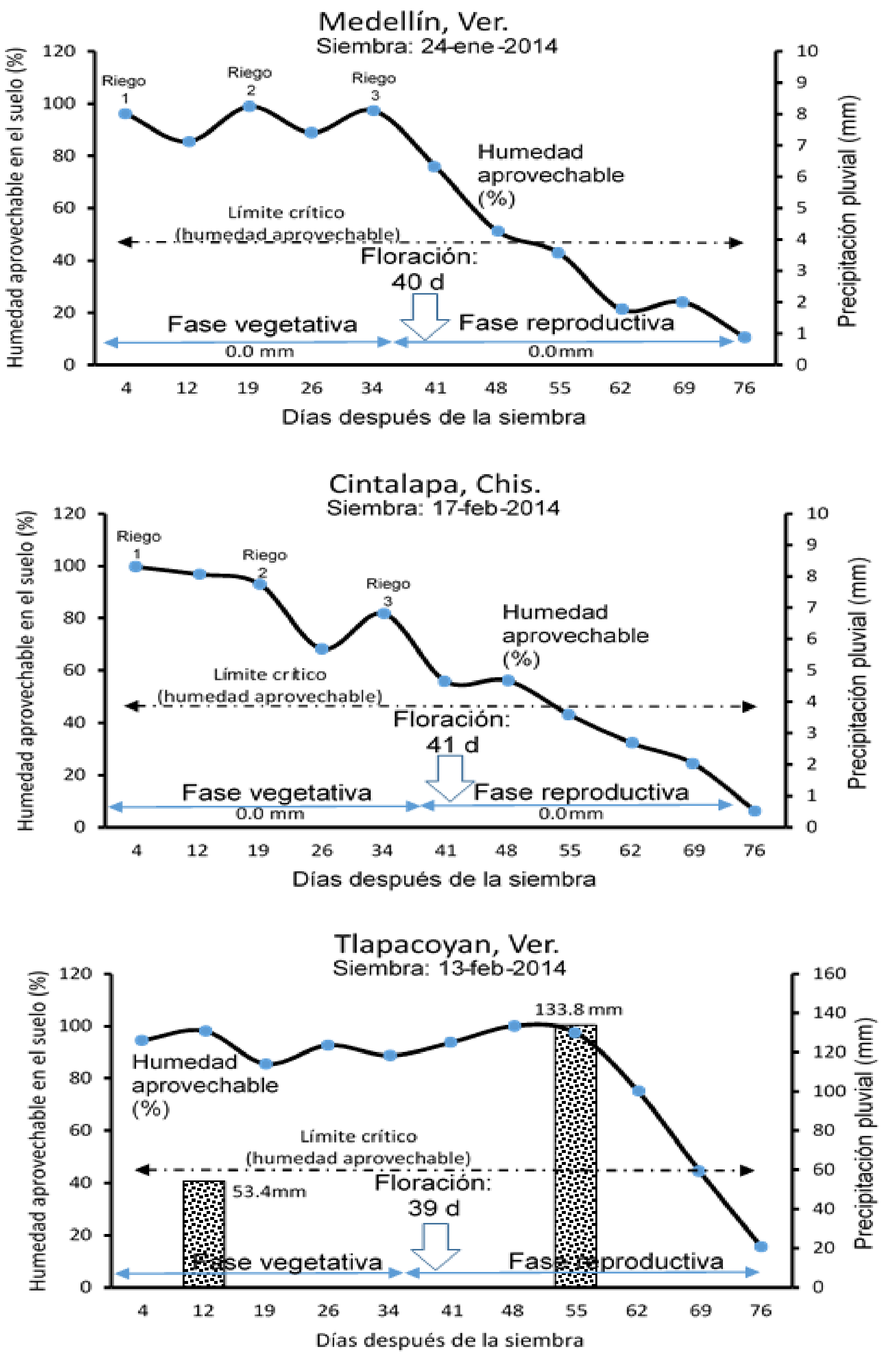

Figure 2. Rainfall occurred and usable soil moisture in Cintalapa, Medellín and Tlapacoyan, during the spring-summer 2014 cycle.

The Verdín variety, together with the SEN-56 line, were the earliest genotypes to reach maturity, both under drought conditions and without humidity stress, although under this latter condition, the genotypes showed a lower precocity, due to a higher better distribution of rainfall during the crop cycle. On average of the six test environments, these two genotypes reached maturity before 69 dds, a significantly shorter time than that of seven other lines and the commercial varieties Negro Tacaná and Negro Jamapa (Table 2). The precocity of Verdín and SEN-56, has been documented in evaluation studies conducted in the state of Veracruz (Tosquy e*t al*., 2014), which is important to avoid terminal drought, since it allows bean plants complete its cycle and escape the drought before critical problems arise due to lack of humidity (Acosta-Díaz *et al*., 2004; 2011; Acosta Gallegos and Kelly, 2012). In turn, the genotypes with the greatest number of days to reach maturity under moisture-limiting conditions generally show lower productivity (Zilio *et al*., 201).

Table 2. Days at physiological maturity of 13 genotypes of black beans in four environments with terminal drought and two without drought, in Veracruz and Chiapas, Mexico. Cycles Autumn-Winter 2013 and Spring-Summer 2014.

Genotype	With terminal drought				Average (d)	Without drought		Average (d)	General average (d)
	Medellín (AW, 2013)	Ocozocoautla (AW, 2013)	Medellín (SS, 2014)	Cintalapa (SS, 2014)		Tlapacoyan (AW, 2013)	Tlapacoyan (SS, 2014)		
NGO 17-99	71.67*	70.33*	69	70*	70.25*	81.33*	73.33*	77.33*	72.61*
ELS 9-27	68.67*	69*	67	67.67*	68.08	82*	73.67*	77.83*	71.33
Jamapa Plus	70*	69.33*	71*	70*	70.08*	81.67*	74*	77.83*	72.67*
NGO 07022	71.67*	66	72.67 *	70*	70.08*	81*	74.33*	77.67*	72.61*
CIAT-103-25	69.67*	69.33*	70.33	70*	69.83*	81*	72.67	76.83	72.17*
SEQ-344-21	70*	69.67*	71.67*	70*	70.33*	81.33*	74*	77.67*	72.78*
SCN-2	67	64	73*	63.33	66.83	80.67*	72	76.33	70
SEN-56	63.67	65	70.67	63.33	65.67	78	70	74	68.44
Verdín (SEN-70)	63	66	64	60.67	63.42	79	69.33	74.17	67
NCB-229	71.67*	64.67	72*	70*	69.58*	80.67*	74.33*	77.5*	72.22*
X02-33-153	69.67*	66.67	72.67*	70*	69.75*	81.33*	73*	77.17*	72.22*
N. Tacaná	71.67*	69.67*	73.67*	70*	71.25*	81.67*	73*	77.33*	73.28*
N. Jamapa	71.33*	69.67*	71.67*	70*	70.67*	82*	75*	78.5*	73.28*
Ambient (d)	69.21	67.64	70.72	68.08		80.9*	72.97		71.59
ANVA	**	**	**	**	**	**	**	**	**
DMS 0.05	3.034	2.415	2.695	3.973	2.794	1.603	2.175	1.411	1.928

AW= autumn-winter cycle; SS= spring-summer cycle; **= highly significant difference; *=statistically superior genotypes, according to the minimum significant difference (0.05).

The grain yield showed a significant difference ($p \leq 0.01$) between environments and genotypes, in the two humidity conditions and in the joint analysis of the six evaluation environments. The highest averages were obtained in Tlapacoyan, in the autumn-winter cycle of 2013 and spring-summer of 2014, which were higher than those obtained in the four environments where terminal drought occurred (Table 3). This was due to the fact that in Tlapacoyan, in both production cycles, there was an adequate distribution of rainfall, mainly from the stages of flowering to pod filling, during which time the crop received 92 and 91.7 mm of rainfall in autumn-winter of 2013 and spring-summer of 2014, respectively, sufficient quantities for the filling of pods (López *et al*., 2008), as well as there was more usable soil moisture for the bean plants (Figures 1 and 2).

The lowest average yield was obtained in Ocozocoautla Autumn-Winter cycle of 2013 (Table 3), due to the severe terminal drought and the soil has low moisture retention capacity, due to its high percentage of sand and low content of organic matter. These soil characteristics imply low usable humidity for the crop, and in this case the occurrence of drought during the reproductive stage of the crop (Figure 1), affected grain yield (Acosta-Díaz *et al*., 2009). In Medellin, in both production cycles, there was less rainfall than in Ocozocoautla in Autumn-Winter of 2013; however, the yield was higher, mainly due to the fact that the soil where the trial was established is a river vega, with a high content of organic matter and a frank texture, which gives it a greater moisture retention capacity than that of Ocozocoautla.

Table 3. Grain yield (kg ha^{-1}) of 13 black bean genotypes evaluated in four environments with terminal drought and two without drought, in Veracruz and Chiapas, Mexico. Cycles Autumn-Winter 2013 and Spring-Summer 2014.

Genotype	With terminal drought				Average (kg ha^{-1})	Without drought		Average (kg ha^{-1})	General average (kg ha^{-1})
	Medellín (AW, 2013)	Ocozocoautla (AW-2013)	Medellín (SS-2014)	Cintalapa (SS-2014)		Tlapacoyan (OI-2013)	Tlapacoyan (PV-2014)		
NGO 17-99	1141.33*	622.67	1204.33*	1135.33*	1025.92*	1279.33*	1428.67	1354	1135.28*
ELS 9-27	719.67	510.67	771.33	991.67	748.33	998	1386.33	1192.17	896.28
Jamapa Plus	1218.33*	530.67	881.67	824.67	863.83	1263*	1176	1219.5	982.39
NGO 07022	1034*	624	899.67	1088.33	911.50	1329.33*	1191	1260.17	1027.72
CIAT-103-25	998	501.33	659.33	1113.33*	818	840	1218.33	1029.17	888.39
SEQ-344-21	1009.33	613.33	846.67	1082.67	888	885.67	1300	1092.83	956.28
SCN-2	1043.67*	625.33	950	1401.33*	1005.08*	1271.33*	1341	1306.17	1105.44*
SEN-56	1057.33*	606.67	1182.67*	804	912.67	1262*	1390	1326	1050.44
Verdín (SEN-70)	1253.33*	686.67	1139.67*	1407*	1121.67*	1427.33*	1709*	1568.17*	1270.5*
NCB-229	840.67	568	957	1178*	885.92	1241.33*	1139.33	1190.33	987.39
X02-33-153	1044.33*	538.67	840.33	693.33	779.17	1337*	1445.33	1391.17	983.17
N. Tacaná	747	468	713.33	1064.67	748.25	1199.67*	1470.67	1335.17	943.89
N. Jamapa	854.33	549.33	1024	738.33	791.5	1318*	924.33	1121.17	901.39
Ambient (d)	997.02	572.72	928.46	1040.2		1204*	1316.92*		1009.89
ANVA	**	ns	**	**	**	**	**	**	**
DMS 0.05	224.744		167.961	318.319	205.268	281.167	145.992	154.469	171.886

AW= Autumn-Winter cycle; SS= Spring-Summer cycle; **= highly significant difference; ns= non-significant difference; *= statistically superior genotypes, according to the minimum significant difference (0.05).

The variety Verdín, together with the lines NGO-17-99 and SCN-2, obtained an average performance significantly outstanding in conditions of terminal drought, while, without the presence of drought, Verdín was the most productive. This variety obtained the highest average yield of the six test environments, which was statistically similar to that of NGO-17-99 and SCN-

2 and superior to those of the rest of the genotypes (Table 3). According to the parameters of stability, all the genotypes were stable in their performance; that is, they presented a low interaction with the environments in which they developed, since their regression coefficients and regression deviations were: bi= 1 and S^2di= 0 (Eberhart y Russell, 1966). The stability characteristic of the Negro Tacaná and Negro Jamapa commercial varieties had already been documented previously (López *et al*., 2001; 2007b).

These results indicate that Verdín, NGO-17-99 and SCN-2 adapt to the environmental conditions of the humid tropics of Veracruz and Chiapas and have greater yield potential than the commercial varieties of current use in both entities. However, the NGO-17-99 line has a significantly longer maturity cycle than that of the Verdín variety, while the grain of the SCN-2 line is larger (>25 g per 100 seeds) than the demanded by producers and consumers in the states of Veracruz and Chiapas (López *et al*., 2012). Therefore, the new Verdín variety is considered superior.

The Verdín variety, due to its characteristics of precocity and tolerance to conditions of humidity stress (Tosquy *et al*., 2014; López *et al*., 2015; Tosquy *et al*., 2016a), will allow the producer to reduce risks of yield loss for periods of terminal drought, as well as harvesting up to 10 days earlier than with other varieties and obtaining greater grain yield, with and without the presence of terminal drought stress, than with Negro Jamapa and Negro Tacaná varieties and other materials commonly used in Veracruz and Chiapas (Tosquy *et al*., 2016b). In addition, the grain of the variety Verdín, gathers the characteristics of bean type, black, opaque and of small size (<25 g per 100 seeds), which consumers demand in the southeast of Mexico and its technological quality of grain (data not shown), is similar to that of the Negro Jamapa variety (Tosquy *et al*., 2016b).

Conclusions

The differences in moisture availability during the reproductive stage; through, the test sites affected the productive response and the duration of the crop cycle of the evaluated genotypes, to higher stress due to drought, lower yield and shorter cycle.

The variety Verdín, together with the lines NGO-17-99 and SCN-2, obtained an average yield significantly superior to the rest of the genotypes in the test locations with conditions of terminal drought, while, in the localities without presence of drought, Verdín was the most productive.

The Verdín variety showed a shorter cultivation cycle than the rest of the genotypes under evaluation, a phenological characteristic that partially allowed it to escape the terminal drought.

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