Article

Yield and resistance to golden yellow mosaic of tropical black bean genotypes

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Abstract

In the tropical areas of Chiapas, Mexico, bean production is affected by golden yellow mosaic, drought and soil acidity. The objective of this research was to identify bean genotypes resistant to the golden yellow mosaic, with higher productivity than the Negro Jamapa variety, commonly sown in Chiapas. In the autumn-winter of 2019-20 20, an experiment was established in three localities in central Chiapas, 11 lines and three varieties of black bean, including Negro Jamapa, were evaluated. The experimental design was randomized blocks with three repetitions. The incidence of golden yellow mosaic and grain yield were quantified. Data from the three localities were analyzed individually and in combination. Correlation analyses between the incidence of golden yellow mosaic and genotype yield were also performed. The golden yellow mosaic significantly reduced yield at the three sites of evaluation (Villa Corzo, r= -0.562*; CECECH, r= -0.757** and El Gavilán, r= -0.552*). The Jamapa Plus/XRAV-187-3-4-1 line showed the greatest damage from this disease with an average incidence score of 6, significantly higher than those of the rest of the genotypes, while the lines: Negro Citlali/XRAV-187-3-1-6, Papaloapan/SEN 46-7-7 and Jamapa Plus/XRAV-187-3-4-4 and the Verdín variety showed the highest resistance to the golden yellow mosaic, with incidence scores between 1.67 and 3.22, statistically lower than that of the control Negro Jamapa. These four genotypes also obtained average yields that were significantly outstanding (greater than 934 kg ha^{-1}) and higher than that of Negro Jamapa.

Keywords: *Phaseolus vulgaris* L., BGYMV, productive behavior.

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Introduction

Due to its high commercial demand, in southeastern Mexico most farmers sow opaque black grain bean (FIRA, 2016). Chiapas is one of the most important producers, in 2019, 114 612 ha were sown in this state, of which 71 978 ha were cultivated in the summer cycle, under rainfed conditions and the rest in the autumn-winter cycle, with residual moisture, the average yield in both conditions was less than 600 kg ha^{-1} (SIAP, 2020).

The low yield observed is a consequence of biotic, abiotic, technical and socioeconomic factors. Among the biotic ones, viral diseases stand out, particularly the golden yellow mosaic caused by the bean golden yellow mosaic virus (BGYMV), which is transmitted by whiteflies [*Bemisia tabaci* (Gennadius)]. This disease has been present since 1977 in Veracruz, Chiapas, Yucatán, Tamaulipas and in the Huastecas (Cuéllar and Morales, 2006), both in the sowings under rainfed and residual moisture conditions and can cause up to 100% losses in yield when it occurs from the vegetative phase of the crop (Villar *et al*., 2003). The control of BGYMV has focused on the development of resistant varieties (Morales and Anderson, 2001; Soler-Garzón *et al*., 2021).

Among the abiotic factors are the frequent occurrence of periods of terminal and intermittent drought, which, depending on their intensity and magnitude, can cause losses of 20 to 100% of grain yield (Frahm *et al*., 2003; López *et al*., 2008), as well as the sowing of bean in acidic soils, which limit plant development and yield, due to low nutrient availability, mainly of the exchangeable bases calcium, magnesium and potassium (Villar *et al*., 2003; Aye *et al*., 2017).

Another limiting factor is the sowing of landrace materials that are low yielding, limited in adaptation and susceptible to diseases (Ugalde *et al*., 2014) and varieties such as Negro Jamapa, generated in 1958 (Rosales *et al*., 2004). This variety is sown in Chiapas and other states of the Mexican tropics because its grain is in high demand, but it is susceptible to the main viral and fungal diseases present in Chiapas and has poor adaptation to drought conditions and acidic soils (Rodríguez and Yoshii, 1990; Tosquy *et al*., 2008; 2014). Considering that, in Chiapas, most bean producers are oriented to self-consumption and sow on areas of less than 1 ha with limited economic resources, the use of improved varieties of high yield and tolerant to the limiting factors indicated represents the most viable alternative to contribute to mitigate the low productivity of the crop in the state (López *et al*., 2012).

Currently, the Bean Program for southeastern Mexico has a group of advanced lines of black bean, generated by the National Bean Program of INIFAP, which were selected for their high yield potential, less interaction with the environment and some of them, for the presence of the molecular marker (MM) SR2 linked to the *bgm-1* gene that gives resistance to BGYMV (Anaya *et al*., 2018; Tosquy *et al*., 2019). The objective of this research work was to identify genotypes (lines or varieties) of black bean resistant to the golden yellow mosaic, with greater yield potential than the Negro Jamapa variety, under the environmental conditions in which the bean is sown in the state of Chiapas.

Materials and methods

The study included 14 genotypes of tropical black bean: 11 advanced lines (five derived from the Negro Papaloapan/SEN 46 cross, three from the Negro Citali/XRAV-187-3 cross and three from the Jamapa Plus/XRAV-187-3 cross), the improved varieties Negro Medellín and Verdín, included for their good productive behavior and adaptation to the tropical areas of the states of Chiapas and Veracruz (López *et al*., 2000; Tosquy *et al*., 2016) and Negro Jamapa used as a control for being one of the most sown varieties in Chiapas (López *et al*., 2006).

The field trial was established in three localities in the central zone of the state of Chiapas during the autumn-winter cycle (September-December) of 2019-2020 and was conducted in conditions of residual moisture; that is, using the moisture stored in the soil and the water of the last rains of the rainfed cycle.

The soil of the experimental site of Villa Corzo is a chromic Luvisol, of sandy crumb texture, with a pH of 4.79, classified as strongly acidic, according to the Official Mexican Standard PROY-NOM-021-RECNAT-2000, the soil of the Centro de Chiapas Experimental Field (CECECH, for its acronym in Spanish) is a pelic epileptic Vertisol, of sandy-clay crumb texture, with a pH of 5.74, classified as moderately acidic, and that of El Gavilán is a pelic calcaric vertisol, of clayey crumb texture, with a pH of 4.26, classified as strongly acidic (NOM 021-RECNAT-2000, 2000). Table 1 shows the geographical location and some climatic characteristics of the evaluation localities.

Table 1. Location and climatic characteristics of the experimental sites where the field trial was conducted in the state of Chiapas. Autumn-winter cycle of 2019-2020.

Locality	Geographic coordinates	Altitude (m)	Annual rainfall (mm)	Average annual temperature (°C)
Villa Corzo†	16° 11’ NL and 93° 16’ WL	569	1156.7	25.1
CECECH ‡	16° 46’ NL and 93° 24’ WL	796	878.1	22.7
El Gavilán‡	16° 44’ NL and 93° 26’ WL	760	890.5	23.6

†= municipality of Villa Corzo; ‡= municipality of Ocozocoautla. CECECH= Centro de Chiapas Experimental Field (Serrano *et al*., 2006).

The bean genotypes were sown in September 2019, at a density of 250 000 plants ha^{-1}, in a randomized block experimental design with three repetitions and experimental plots of three furrows of 5 m in length, where the useful plot corresponded to the complete central furrow.

During the conduct of the trial, rainfall was quantified, the incidence of golden yellow mosaic in the R8 stage was determined with the general scale of 1 to 9 for the evaluation of viral diseases, where 1 and 9 correspond to 0% and 100% incidence, respectively (Van and Pastor, 1987) and the grain yield expressed in kilograms per hectare at 14% of moisture.

An analysis of variance of the variables quantified by locality and a combined analysis of the three test environments were performed, for the separation of means, the test based on the least significant difference at 5% probability of error (LSD, $\alpha = 0.05$) was applied (SAS Institute, 1999).

Correlation analyses between the average values of golden yellow mosaic incidence and grain yield of the genotypes in each locality were also performed, to determine specifically, in which evaluation localities, the BGYMV was negatively and significantly related to bean yield.

Results and discussion

In the three test localities, a highly significant effect ($p \leq 0.01$) on the incidence of golden yellow mosaic was detected between treatments. With respect to grain yield, only in the CECECH locality was high significance ($p \leq 0.01$) detected between treatments, while in Villa Corzo and El Gavilán, the effect was significant ($p \leq 0.05$) (Table 2).

Table 2. Mean squares and statistical significance of golden yellow mosaic incidence and grain yield of black bean genotypes evaluated in three localities of the state of Chiapas. Autumn-winter cycle of 2019-2020.

SV	DF	Villa Corzo	CECECH	El Gavilán
		Incidence of golden yellow mosaic		
Treatments	13	2.293039**	6.893771**	4.65201**
Blocks	2	0.380951	0.5	0.071442
Error	26	0.227107	0.525642	0.327841
Total	41			
CV (%)		14.94	21.15	13.82
		Grain yield		
Treatments	13	51 111.08*	12 2748.62**	17 181.08*
Blocks	2	46 304	6 890	4 715
Error	26	18 195.54	22 257.08	7 330.15
Total	41			
CV (%)		15.93	14.94	10.21

The golden yellow mosaic significantly reduced grain yield in the three test localities (Villa Corzo r= -0.562*, CECECH r= -0.757** and El Gavilán r= -0.552*), which could be due to the fact that whiteflies and the symptoms were present from the V4 stage of the bean, which is when this disease can cause greater damage to bean plants (López *et al*., 2002). The presence of the vector and incidence of symptoms in the early stages of the development of the plant help to ensure that the evaluation was carried out under conditions of disease pressure.

Table 3 shows that, in the three evaluation sites, Jamapa Plus/XRAV-187-3-4-1 showed the greatest damage from this disease, with incidence values of 5 in Villa Corzo and above 6 in CECECH and El Gavilán, indicating that this genotype was the most susceptible to the golden yellow mosaic. The Negro Papaloapan/SEN 46-3-2 line also showed significant damage in the CECECH locality with intermediate symptoms of the disease.

Table 3. Incidence of golden yellow mosaic in 14 black bean genotypes in three localities of the state of Chiapas. Autumn-winter cycle of 2019-2020.

Genotype	Villa Corzo	CECECH	El Gavilán	Average
Negro Papaloapan/SEN 46-2-6	3.67	4.67	3.67	4 bcde
Negro Papaloapan/SEN 46-3-2	4	5.33*	3.67	4.33 bcd
Negro Papaloapan/SEN 46-7-7	2	1.33	3	2.11 gh
Negro Papaloapan/SEN 46-7-10	2.67	3	4.33	3.33 cdef
Negro Papaloapan/SEN 46-7-12	3	3.33	4.33	3.56 bcdef
Negro Citlali/XRAV-187-3-1-5	3	2	4	3 efg
Negro Citlali/XRAV-187-3-1-6	1.67	2	1.33	1.67 h
Negro Citlali/XRAV-187-3-1-8	3.33	2.33	4.67	3.44 cdef
Jamapa Plus/XRAV-187-3-1-2	3.33	3.33	5	3.89 bcde
Jamapa Plus/XRAV-187-3-4-1	5*	6.33*	6.67*	6 a
Jamapa Plus/XRAV-187-3-4-4	3	2.33	4.33	3.22 defg
Negro Medellín	4	4.67	5.33	4.67 b
Negro Jamapa	3.67	5	4.67	4.44 bc
Verdín	2.33	2.33	3	2.56 fgh
Environment average	3.19 b	3.43 b	4.14 a	3.59
ANVA	**	**	**	**
CV (%)	14.94	21.15	13.82	16.73
LSD (0.05)	0.8	1.217	0.961	1.134
Correlation coef. BGYMV *vs* GY	-0.562*	-0.757**	-0.552*	-0.699**

The values recorded correspond to the incidence scale of 1 to 9 (van Schoonhoven and Pastor-Corrales, 1987). *= $p \leq 0.05$. **= $p \leq 0.01$. Means with equal letters in the row of environment averages and in the column of genotype averages are not statistically different according to the least significant difference (LSD, 0.05).

In the joint analysis of golden yellow mosaic incidence, a significant effect was detected in the locality factor and a highly significant effect in the genotype factor and in the interaction of both factors. With respect to the first factor, in the locality of El Gavilán, there was the highest incidence of this disease, with an average value of 4.14, significantly higher than those registered in CECECH and Villa Corzo, which had an average value of 3.43 and 3.19, respectively (Table 3), a value of 3 in the general scale of evaluation for viral diseases corresponds to an incidence between 11 and 25%, while one of 4 to an incidence between 26 and 40%, so these values can be considered as a low and medium incidence, respectively, since a value of 8 or 9 on the scale correspond to incidences between 91 and 100% (Van and Pastor, 1987).

This could be due to the fact that, in El Gavilán, there was less moisture (83 mm of rainfall) and slightly higher average temperatures prevailed (25.1 °C) during the vegetative phase of the crop (Table 4), which favored the reproduction of the whitefly (*B. tabaci*) and consequently, the incidence of golden yellow mosaic increased, since the incidence of this disease is directly related to the populations of *B. tabaci* (Morales and Anderson, 2001); likewise, the occurrence of periods of drought, accompanied by high temperatures, favor the reproduction of *B. tabaci* (Cuéllar and Morales, 2006).

Table 4. Rainfall occurred and average temperature prevailing at the experimental sites where the uniform yield trial was conducted in the state of Chiapas. Autumn-winter cycle of 2019-2020.

Locality	Date of sowing	Vegetative phase		Reproductive phase		Total R in the cycle (mm)
		R (mm)	AT (°C)	R (mm)	AT (°C)	
Villa Corzo†	12-09-2019	118	24.1	66	23.7	184
CECECH‡	13-09-2019	86	23.6	130	23.2	216
El Gavilán‡	27-09-2019	83	25.1	142	24.8	225

†= municipality of Villa Corzo. ‡= municipality of Ocozocoautla. CECECH= Centro de Chiapas Experimental Field; R= rainfall; AT= average temperature.

In the genotype factor, the lines Negro Citlali/XRAV-187-3-1-6, Negro Papaloapan/SEN 46-7-7, Negro Citlali/XRAV-187-3-1-5 and Jamapa Plus/XRAV-187-3-4-4, as well as the Verdín variety, were the most resistant to this viral disease, with average incidence scores between 1.67 and 3.22, significantly lower than that of the Negro Medellín and Negro Jamapa varieties, and that of the Jamapa Plus/XRAV-187-3-4-1 line, this last line obtained the highest average incidence value (6), which was significantly higher than the rest of the genotypes (Table 3).

The good reaction to the golden yellow mosaic of Negro Citlali/XRAV-187-3-1-6, Negro Citlali/XRAV-187-3-1-5 and Verdín is largely due to the fact that their plants have the co-dominant MM SR2, linked to the *bgm-1* gene, which gives them genetic resistance to BGYMV (Urrea *et al*., 1996; Anaya *et al*., 2018). In the case of Negro Papaloapan/SEN 46-7-7 and Jamapa Plus/XRAV-187-3-4-4, which, in a first scrutiny, were negative for the presence of MM SR2 (Anaya *et al*., 2018), their good reaction to the golden yellow mosaic may be due to the fact that these lines contain other genes or mechanisms of resistance that contributed to a more stable resistance response across environments, which is likely, since their progenitors, Negro Papaloapan, in the case of the first line and XRAV-187-3 of the second, in addition to having the *bgm-1* gene, have the major QTL of resistance to BGYMV (Anaya *et al*., 2018).

The statistical significance of the locality x genotype interaction was due to differences in the values of incidence of golden yellow mosaic of some genotypes across the test localities, which was more noticeable in the Negro Citlali/XRAV-187-3-1-8 and Jamapa Plus/XRAV-187-3-1-2 lines, which, in CECECH and Villa Corzo, had low incidence of this disease, with average scores that varied between 2.33 and 3.33, while in El Gavilán, they obtained average scores of 4.67 and 5.0, respectively, as well as in the Negro Jamapa and Negro Medellín varieties, which had a 'moderate' incidence in Villa Corzo, with scores of 3.67 and 4.0, respectively, and 'intermediate' in CECECH and El Gavilán, with scores that ranged from 4.67 to 5.33 (Van and Pastor, 1987) (Table 3).

With respect to grain yield, in each of the test localities, the outstanding group of genotypes (four in Villa Corzo, four in CECECH and eight in El Gavilán) statistically exceeded the yield of the Negro Jamapa and Negro Medellín varieties, Table 5. Of these three groups, the following lines stand out: Jamapa Plus/XRAV-187-3-4-4 and Negro Papaloapan/SEN 46-7-7, which, although lacking MM SR2 linked to the *bgm-1* gene, obtained a significantly

outstanding grain yield in the three test localities, the Jamapa Plus/XRAV-187-3-1-2 and Negro Citlali/XRAV-187-3-1-6 lines and the Verdín variety were also in the outstanding group in CECECH and El Gavilán (Table 5).

Table 5. Grain yield of black bean genotypes evaluated in three localities of the state of Chiapas. Autumn-winter cycle of 2019-2020.

Genotype	Villa Corzo	CECECH	El Gavilán	Average
Negro Papaloapan/SEN 46-2-6	802.67	724	813.67	780.11 def
Negro Papaloapan/SEN 46-3-2	851.67	792.67	987.33*	877.22 cdef
Negro Papaloapan/SEN 46-7-7	1 079.33*	1 268.67*	862*	1 070 ab
Negro Papaloapan/SEN 46-7-10	924*	1 048	802.67	924.89 abcde
Negro Papaloapan/SEN 46-7-12	756.67	1 033.33	873.67*	887.89 bcdef
Negro Citlali/XRAV-187-3-1-5	739	957.33	898.33*	864.89 cdef
Negro Citlali/XRAV-187-3-1-6	837.33	1 154.67*	879.67*	957.22 abcd
Negro Citlali/XRAV-187-3-1-8	887.33	1 056	828.67	924 abcde
Jamapa Plus/XRAV-187-3-1-2	810	1 310*	848.67*	989.56 abc
Jamapa Plus/XRAV-187-3-4-1	681.33	860	747.33	762.89 ef
Jamapa Plus/XRAV-187-3-4-4	1 125.67*	1 244.67*	897*	1 089.11 a
Negro Medellín	737	754	680.67	723.89 f
Negro Jamapa	719.33	734.67	760.33	738.11 f
Verdín	903.33*	1 042.67	858*	934.67 abcde
Average of environment	846.76 b	998.62 a	838.43 b	894.6
ANVA	*	**	*	**
CV (%)	15.93	14.94	10.21	14.11
LSD (0.05)	226.44	250.44	143.73	185.4

Values expressed in kilograms per hectare. *= $p \leq 0.05$. **= $p \leq 0.01$. Means with equal letters in the row of environment averages and in the column of genotype averages are not statistically different according to the least significant difference (LSD, 0.05).

The fact that lines lacking MM SR2 have stood out for their higher yield under golden yellow mosaic pressure conditions, compared to lines that have this marker, highlights the importance of confirming resistance by confronting the pathogen, since although *bgm-1* is the most widely used gene, MM SR2, according to current standards, is not closely linked to this gene (~3-7 cM), resulting in the selection of a few lines that have the marker, but are nevertheless susceptible to the virus, in addition to the existence of other genes and QTLs whose accumulation conditions high levels of resistance to BGYMV (Soler-Garzón *et al*., 2021), as well as other mechanisms of resistance to the vector, such as antibiosis or antixenosis (Santos *et al*., 2020), whose presence in the evaluated materials needs to be studied.

According to the combined analysis, yield varied significantly between localities ($p \leq 0.05$), genotypes ($p \leq 0.01$) and in the interaction of both factors ($p \leq 0.01$). In the same Table 5, it was observed that the highest average yield was obtained in the CECECH locality, due in large part to

better conditions of soil pH (Table 1) and moisture during the reproductive phase of the crop, in which the bean had 130 mm of rainwater, of an accumulated total of 216 mm in the cycle (Table 4), which favored the filling of pods and therefore, the grain yield (López *et al*., 2008).

In El Gavilán and Villa Corzo, the average yields obtained were statistically similar to each other, and lower than that of CECECH, mainly due to the fact that the soil where the trial was conducted in both locations is strongly acidic (Table 1), which limits the development and productivity of the crop, due to a low availability of exchangeable bases (K^{+}, Ca^{++} and Mg^{++}) for bean nutrition and in some cases, also due to a high saturation of aluminum that some acidic soils of the regions of La Frailesca and central Chiapas may contain, which can cause toxicity to bean plants and reduced root growth (Villar, 2000).

In general, the average grain yields obtained in the three localities were relatively low, due in large part to a low availability of moisture in the crop cycle (Table 4), since, for an adequate development of the bean, at least 300 mm of rainfall, well distributed during the phenological cycle, is required (Ruíz *et al*., 2013). In the genotype factor, a group of six lines and the Verdín variety obtained average grain yields statistically similar to each other and higher than those of the Negro Medellín and Negro Jamapa varieties, in this group, the most productive were the Jamapa Plus/XRAV-187-3-4-4 and Negro Papaloapan/SEN 46-7-7 lines with average yields greater than 1 000 kg ha^{-1} (Table 5).

The two varieties indicated above, along with the Jamapa Plus/XRAV-187-3-4-1 line, obtained the lowest grain yields, Table 5, in large part, because they were the most affected by the golden yellow mosaic; that is, the plants of these genotypes, on average, had a higher incidence of this disease, which, in general, was negatively related to grain yield ($r= -0.699^{**}$) (Table 3).

The highly significant effect of the interaction of both factors indicated that the productive response of some genotypes varied with the environment of evaluation, notorious examples of this behavior were observed in Negro Papaloapan/SEN 46-3-2, which, in El Gavilán, was the most yielding genotype, which is attributed to its good response in conditions of severe edaphic acidity (pH of 4.26), while in CECECH, with better soil acidity conditions for the proper development of the bean (pH of 5.74), it was one of the least productive (Table 5), mainly due to the damage caused by the golden yellow mosaic; as well as in Negro Papaloapan/SEN 46-7-10, which, in the locality of Villa Corzo, in conditions of strongly acidic soil (pH of 4.79), obtained a significantly outstanding grain yield, while in El Gavilán, under conditions of even more severe soil acidity, it was one of the least productive (Table 5), partly also because in that locality it showed a higher incidence of golden yellow mosaic than in the other two localities (Table 3).

Conclusions

In the conditions of moisture and acidic soils of the state of Chiapas, the Verdín variety represents a better crop option than the Negro Jamapa variety. The Jamapa Plus/XRAV-187-3-4-4, Negro Papaloapan/SEN 46-7-7 and Negro Citlali/XRAV-187-3-1-6 lines, and the Verdín variety were resistant to golden yellow mosaic and had significantly higher grain yield than the control variety.

Cited literature

Anaya, L. J. L.; Garrido, R. E. R.; Chiquito, A. E.; Tosquy, V. O. H.; Ibarra, P. F. J. y López, S. E. 2018. Identificación de líneas recombinantes de frijol negro opaco resistentes a BCMV, BCMNV y BGYMV mediante marcadores moleculares. Rev. Mex. Cienc. Agríc. 9(3):601-614. http://dx.doi.org/10.29312/remexca.v9i3.1219.

Aye, N. S.; Butterly, C. R.; Sale, P. W. G. and Tang, C. 2017. Residue addition and liming history interactively enhance mineralization of native organic carbon in acid soils. Biol. Fert. Soils. 53(1):61-75. https://doi.org/10.1007/s00374-016-1156-y.

Cuéllar, M. E. y Morales, F. J. 2006. La mosca blanca *Bemisia tabaci* (Gennadius) como plaga y vectora de virus en frijol común (*Phaseolus vulgaris* L.). Rev. Colombiana de Entomología. 32(1):1-9.

FIRA. 2016. Fideicomiso Instituido en relación con la Agricultura. Panorama agroalimentario. Dirección de Investigación y Evaluación Económica y Sectorial. Frijol. Fideicomisos Instituidos en Relación con la Agricultura (FIRA). México. 17-18 pp.

Frahm, M.; Rosas, J. C.; Mayek, N.; López, E.; Acosta, J. A. y Kelly, J. D. 2003. Resistencia a sequía terminal en frijol negro tropical. Agron. Mesoam. 14(2):143-150. https://doi.org/10.15517/am.v14i2.11942.

López, S. E.; Becerra, L. E. N.; Cano, R. O. y López, G. V. O. 2002. Detección de líneas y variedades de frijol *(Phaseolus vulgaris* L.) con resistencia múltiple a enfermedades en el trópico húmedo de México. Rev. Mex. Fitopatol. 20(2):193-199.

López, S. E.; Cumpían, G. J.; Becerra, L. E. N.; Villar, S. B.; Ugalde, A. F. J. y Acosta, G. J. A. 2000. Adaptación y rendimiento de la variedad de frijol Negro Medellín en el sureste de México. Agron. Mesoam. 11 (2):47-52. https://doi.org/10.15517/am.v11i2.17307.

López, S. E.; Tosquy, V. O. H.; Villar, S. B.; Becerra, L. E. N.; Ugalde, A. F. J. y Cumpián, G. J. 2006. Adaptabilidad de genotipos de frijol resistentes a enfermedades y a suelos ácidos. Rev. Fitotec. Mex. 29(1):33-39.

López, S. E.; Tosquy, V. O. H.; Ugalde, A. F. J. y Acosta, G. J. A. 2008. Rendimiento y tolerancia a sequía de genotipos de frijol negro en Veracruz. Rev. Fitotec Mex. 31(3):35-39.

López, S. E.; Tosquy, V. O. H.; Jiménez, H. Y.; Salinas, P. R. A.; Villar, S. B. y Acosta, G. J. A. 2012. Rendimiento y adaptación de la variedad de frijol 'Negro Comapa' en dos regiones de México. Rev. Fitotec. Mex. 35(4):309-315.

Morales, F. J. and Anderson, P. K. 2001. The emergence and dissemination of whitefly-transmitted geminiviruses in Latin America. Arch. Virol. 146(3):415-441. https://doi.org/10.1007/s007050170153.

Norma Oficial Mexicana. 2002NOM-021-RECNAT-2000. Que establece las especificaciones de fertilidad, salinidad y clasificación de suelos. Estudios, muestreo y análisis. Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). México, DF.

Rodríguez, R. R. y Yoshii, O. K. 1990. Tolerancia varietal del frijol al mosaico dorado y control químico del vector *Bemisia tabaci* Genn. en Papantla, Veracruz. Agric. Téc. Méx. 16(1):19-32.

Rosales, S. R.; Acosta, G. J. A.; Muruaga, M. J. S.; Hernández, C. J. M.; Esquivel, E. G. y Pérez, H. P. 2004. Variedades mejoradas de frijol del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Secretaría de Agricultura Ganadería Pesca y Alimentación (SAGARPA). Campo Experimental Valle de México (CEVAMEX). Chapingo, Estado de México, México. Libro técnico núm. 6. 80-110 pp.

Ruíz, C. J. A.; Medina, G. G.; González, A. I. J.; Flores, L. H. E.; Ramírez, O. G.; Ortiz, T. C.; Byerly, M. K. F. y Martínez, P. R. A. 2013. Requerimientos agroecológicos de cultivos. 2da. (Ed). INIFAP. CIRPAC. Campo Experimental Centro Altos de Jalisco. Tepatitlán de Morelos, Jalisco, México. Libro técnico núm. 3. 211-217 pp.

SAS Institute. 1999. Institute Statistical Analysis Systems. SAS/STAT user's guide. Versión 8.0. SAS Institute. Cary, NC, USA.

Santos, T. L. B.; Baldin, E. L. L.; Ribeiro, L. P.; Souza, C. M.; Bueno, N. M. and Silva, I. F. 2020. Silverleaf whitefly-resistant common beans: an investigation of antibiosis and/or antixenosis. Bragantia. 79(1):62-73. https://doi.org/10.1590/1678-4499.20190309.

Serrano, A. V.; G. Díaz, P. G.; López, L. A.; Cano, G. M. A.; Báez, G. A. D. y Garrido, R. E. R. 2006. Estadísticas climatológicas básicas del estado de Chiapas (período 1961-2003). SAGARPA. INIFAP. CIRPAS. Campo Experimental Centro de Chiapas. Ocozocoautla de Espinosa, Chiapas, México. Libro técnico núm. 1. 57-142 pp.

SIAP. 2020. Servicio de Información Agroalimentaria y Pesquera. Avance de siembras y cosechas. Resumen por estado. SIAP. Gobierno de México. http://infosiap.siap.gob.mx:8080/agricola_siap_gobmx/resumenproducto.do.

Soler-Garzón, A.; Oladzad, A.; Beaver, J.; Beebe, S.; Lee, R.; Lobaton, J. D.; Macea, E.; McClean, P.; Raatz, B.; Rosas, J. C.; Song, Q. and Miklas, P. N. 2021. NAC candidate gene marker for *bgm-1* and interaction with QTL for resistance to Bean golden yellow mosaic virus in common bean. Front Plant Sci. 12(1):1-18. https://doi: 10.3389/fpls.2021. 628443.

Tosquy, V. O. H.; Villar, S. B.; Rodríguez, R. J. R.; Ibarra, P. F. J.; Zetina, L. R.; Meza, P. A. y Anaya-López, J. L. 2019. Adaptación de genotipos de frijol negro a diferentes ambientes de Veracruz y Chiapas. Rev. Mex. Cienc. Agríc. 10(6):1301-1312. https://doi.org/10.29312/remexca.v10i6.1658.

Tosquy, V. O. H.; López, S. E.; Villar, S. B.; Acosta, G. J. A. y Rodríguez, R. J. R. 2016. Verdín: variedad de frijol negro tolerante a sequía terminal para Veracruz y Chiapas, México. Rev. Mex. Cienc. Agríc. 7(7):1775-1780. https://doi.org/10.29312/remexca.v7i7.170.

Tosquy, V. O. H.; López, S. E.; Francisco, N. N.; Acosta, G. J. A. y Villar, S. B. 2014. Genotipos de frijol negro opaco resistentes a sequía terminal. Rev. Mex. Cienc. Agríc. 5(7):1205-1217. https://doi.org/10.29312/remexca.v5i7.866.

Tosquy, V. O. H.; López, S. E.; Zetina, L. R.; Ugalde, A. F. J.; Villar, S. B. y Cumpián, G. J. 2008. Selección de genotipos de frijol con adaptación a suelos ácidos. Terra Latinoam. 26(3):227-233.

Ugalde, A. F. J.; López, S. E.; Lépiz, I. R.; Viana, R. A. y Leyva, V. S. 2014. Producción artesanal de semilla de frijol con participación municipal en Veracruz, México. Agron. Mesoam. 25(1):35-44. https://doi.org/10.15517/am.v25i1.14211.

Urrea, C. A.; Miklas, P. N.; Beaver, J. S. and Riley, R. H. 1996. A codominant randomly amplified polymorphic DNA (RAPD) marker useful for indirect selection of bean golden mosaic virus resistance in common bean. J. Am. Soc. Hort. Sci. 121(6):1035-1039. https://doi.org/10.21273/JASHS.121.6.1035.

Van, S. A. y Pastor, C. M. A. 1987. Sistema estándar para la evaluación de germoplasma de frijol. Van Schoonhoven, A. y Pastor-Corrales, M. A. (Comps.). Centro Internacional de Agricultura Tropical (CIAT). Cali, Colombia. 17-19 pp.

Villar, S. B. 2000. Estrategia para el manejo de suelos ácidos en frijol (*Phaseolus vulgaris* L.) en el estado de Chiapas, México. Agron. Mesoam. 11(1):155-158.

Villar, S. B.; López, S. E. y Acosta, G. J. A. 2003. Selección de genotipos de frijol por rendimiento y resistencia al mosaico dorado y suelos ácidos. Rev. Fitotec. Mex. 26(3):109-114.