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Adaptation and Disease Resistance of Elite Tropical Black Bean Lines

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ABSTRACT

Background: Chiapas and Veracruz are the main producing states in the lowlands of southeastern Mexico, with a total harvested volume of 90,146 t of grain in 2020, in a joint planting area of 151,037 ha. However, the cultivation of this legume is subject to a series of biological, climatic and edaphic problems, which make the average yields notoriously low. The objective of this study was to identify high-yielding black bean lines, resistant to diseases and with better adaptation than three commercial cultivars currently used in both entities.

Methods: During 2019 and 2020, in seven environments of Veracruz and Chiapas, 11 lines and the cultivars Negro Jamapa, Negro Medellín and Verdín were evaluated. An analysis of variance of the variables was performed by each environment and combined analysis of the incidence of BGYMV and grain yield.

Result: Jamapa Plus/XRAV-187-3-4-4 was the most productive line, with an average yield of 1,542 kg ha^{-1}, statistically similar to that of Jamapa Plus/XRAV-187-3-1-2 and higher than that of the rest of the genotypes. Both lines showed resistance to web blight and rust and low incidence of BGYMV, diseases that significantly reduced grain yield. Jamapa Plus/XRAV-187-3-1-2 showed stability throughout the evaluation environments.

Key words: Genotypes, *Phaseolus vulgaris* L., Reaction to diseases, Yield stability.

INTRODUCTION

In the Mexican southeast, there is a preference for the small, opaque, black bean (*Phaseolus vulgaris* L.), so most farmers plant varieties of this type of bean. In this region, Chiapas and Veracruz, Mexico, are the main producing states with a total harvested volume of 90,146 t of grain in 2020, in a joint planting area of 151,037 ha (SIAP, 2022). However, the cultivation of this legume is subject to a series of biological, climatic and edaphic problems, which make the average yields notoriously low, 575 and 850 kg ha^{-1}, in Chiapas and Veracruz, respectively (SIAP, 2022).

As far as biological problems, the main limitation is the incidence of viral diseases such as bean golden yellow mosaic (BGYMV) and bean common mosaic (BCMV) and fungal diseases such as rust (*Uromyces appendiculatus* var. *appendiculatus*) and angular leaf spot [*Phaeoisariopsis griseola* (Sacc.) Ferraris] and less frequently, but also important due to the damage they cause, anthracnose [*Colletotrichum lindemuthianum* (Sacc. and Magnus) Lams. Scrib.] and web blight [*Thanatephorus cucumeris* (Frank) Donk]. Regarding climatic problems, the most outstanding one is the occurrence of periods of drought, called terminal, because it generally coincides with the reproductive stage of the crop, which is when the bean is more sensitive to lack of moisture (Acosta *et al*., 2004). In edaphic problems, the main one is the planting of beans predominantly in low fertility and acidic soils, which limit their development, due to low availability of nutrients (Zetina *et al*., 2002). This situation becomes more critical, since most of the local landraces and improved cultivars of black bean *viz*., Negro Jamapa are susceptible to one or more of these limiting factors. Thus, under adverse conditions of diseases, drought and acidic soils, these varieties show a poor response in terms of grain yield (Tosquy *et al*., 2014).

In 2019, a uniform yield trial was established with a group of elite lines of small, opaque, black beans, selected for their resistance to rust and anthracnose under greenhouse conditions (Garrido-Ramírez *et al*., 2020). Some of these elite lines were selected for their tolerance to drought and adaptation to acidic soils (Tosquy *et al*., 2020) and carry the genes *I* and *bgm-1*, which confer resistance to BCMV and BGYMV, respectively (Anaya-López *et al*., 2018). This trial was established in seven environments in

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Veracruz and Chiapas, Mexico, to identify high-yielding black bean lines, with high resistance to fungal and viral diseases and better adaptation as compared to the three popular varieties currently under cultivation.

MATERIALS AND METHODS

The field trial included 11 recombinant lines generated by the National Bean Program of the INIFAP (National Institute of Forestry, Agriculture and Animal Livestock Research) and Negro Jamapa, Negro Medellín and Verdín varieties used as regional checks. Table 1 shows the location and environmental characteristics in which the uniform yield trials were carried out.

The genotypes studied are of indeterminate growth habit, type II, of bushy and erect plants, which were planted at a density of 250,000 plants ha^{-1} in a RCBD with three replicates and experimental units of three rows of 5 m in length, where the useful plot corresponded to the complete central row. The agronomic management was done according to the recommendations made by INIFAP for growing beans in the states of Chiapas and Veracruz (López *et al*., 2017).

During the conduction of the trial, the rainfall was recorded and the incidence of web blight (Fig 1) and rust (Fig 2) diseases was rated in Rincón Grande, in the growing cycles fall-winter (F-W) 2019-20 and winter-spring (W-S) 2020, respectively; and of the bean golden yellow mosaic (Fig 3) in the three environments of the state of Chiapas. The evaluation of these diseases was carried out visually, during the R8 stage (pod filling), using the general scales from 1 to 9 of the International Center for Tropical Agriculture, to evaluate the reaction of bean germplasm to fungal and viral pathogens (van Schoonhoven and Pastor-Corrales, 1987). For the reaction to fungal diseases the 1-3 values indicate resistant (symptoms no visible or very mild), from 4-6 intermediate reaction (visible symptoms that cause limited economic damage) and 7-9 susceptible (severe to very severe symptoms, which cause considerable losses in yield or death of the plant). In regards to viral diseases, 1 corresponds to 0% incidence (absence of symptoms) and 9 to 100% incidence (death of plants). After the harvest was carried out, the grain yield was estimated, which was calculated from the weight of the grain harvested from each useful plot, in kilograms per hectare at 14% humidity.

Fig 1: Incidence of web blight in stage R8, in Rincón Grande site during the 2019-20 fall-winter growing cycle.

Analysis of variance of the variables quantified by evaluation environment and combined analysis (environments-genotypes) of the incidence of bean golden yellow mosaic and grain yield were performed. For the separation of means, the test based on the Least Significant Difference was applied at 5% probability of error (LSD, α= 0.05). Correlation analyzes were also carried out between the average incidence values of each disease and the grain yield of the genotypes in each test site, to determine if they caused significant damage to bean production. Likewise, the additive main effect and multiplicative interaction model (AMMI) was used to classify the environments and identify outstanding genotypes for their grain yield and less interaction with the environment (Gauch and Zobel, 1996; SAS/STAT®, 1999; Vargas and Crossa, 2000).

RESULTS AND DISCUSSION

The reaction of the genotypes to the incidence of diseases varied significantly ($P\leq0.01$) (Table 2). In E1, with residual moisture, the incidence of web blight (Fig 3) at the beginning of stage R8 (pod filling) significantly reduced bean yield (r = -0.81**). The Negro Jamapa variety was found to be most affected by this disease, as it presented statistically significant damages similar to those shown by the three lines from the Negro Citlali/XRAV-187-3 cross and higher than those of the rest of the genotypes did. On the other hand, the three lines derived from the Jamapa Plus/XRAV-187-3 cross, together with the Papaloapan/SEN 46-3-2 and Papaloapan/SEN-46-2-6 lines and the Verdín variety, showed resistance to this disease with average incidence scores between 2.0 and 3.33 (Table 2). The resistance of Verdín and the susceptibility of Negro Jamapa to web blight have been previously reported (Rodríguez *et al*., 2016).

In E7, under irrigation, 15 days after the trial was sown, there was a period of 20 days, in which conditions of relative humidity were greater than 80% and temperatures between 15.4 and 28°C, which favored the incidence of rust (Fig 2) (Schwartz *et al*., 2004). This disease significantly affected bean yield (r = -0.61*), mainly because it appeared from the beginning of the R5 stage (pre-flowering) of the crop, which is when it can cause the greatest damage to bean plants. The Negro Jamapa, Negro Medellín and Verdín varieties and the Negro Citlali/XRAV-187-3-1-8 line showed the highest incidence of this disease. In turn, the three lines from the Jamapa Plus/XRAV-187-3 cross, together with the Negro Citlali/XRAV-187-3-1-5 and Negro Citlali/XRAV-187-3-1-6 lines, showed resistance to rust with incidence scores ranging from 2.33 to 3.33. The other five lines, derived from the Papaloapan/SEN 46 cross, had an intermediate reaction with scores between 3.67 and 4.0 (van Shoonhoven and Pastor-Corrales, 1987) (Table 2). The good reaction of these lines to rust (Fig 2) is largely because they were selected for their resistance to artificial inoculation with the *U. appendiculatus* fungus under greenhouse conditions, where they showed small chlorotic spots without sporulation, a type of hypersensitive reaction (Garrido-Ramírez *et al*., 2020).

In the state of Chiapas, the bean golden yellow mosaic (Fig 3) significantly reduced grain yield in the three test environments (E2 r = -0.56*, E3 r = -0.76** and E4 r = -0.55*), mainly due to the presence of the whitefly [*Bemisia tabaci* (Gennadius)], vector of BGYMV. The symptoms appeared from stage V4 (third trifoliate leaf), which is when this disease can cause greater damage to bean plants (López *et al*., 2002). The incidence of bean golden yellow mosaic varied significantly between environments (P≤0.05) and genotypes (P≤0.01). E4 had the highest incidence of this disease (average 4.14*), which was significantly higher than the other two test environments (Table 2). This could be because there was less humidity in that locality (83 mm rainfall) and slightly higher average temperatures prevailed (25.1°C) during the vegetative phase of the crop than in E3 (86 mm and 23.6 °C) and in E2 (118 mm and 24.1°C). Such conditions favor the reproduction of whitefly and consequently, a higher incidence of bean golden yellow mosaic, since the incidence of this disease is directly related to the *B. tabaci* populations (Morales and Anderson, 2001).

Table 1: Location and characteristics of experimental sites where the uniform yield trial was carried out in the states of Chiapas and Veracruz, Mexico.

Locality/municipality/state	Location (NL-WL)	Altitude (masl)	Cycle/year	Environmental condition
Villa Corzo, Villa Corzo, Chiapas	16°11′-93°16′	569	FW/2019-20	RH, HAS (pH 4.79), OM (0.57%)
CECECH, Ocozocoautla, Chiapas	16°46′-93°24′	796	FW/2019-20	RH, MAS (pH 5.74), OM (0.7%)
El Gavilán, Ocozocoautla, Chiapas	16°44′-93°26′	760	FW/2019-20	RH, HAS (pH 4.26), OM (2.45%)
Rincón Grande, Orizaba, Veracruz	18°51′-97°06′	1,248	FW/2019-20	RH, MAS (pH 6.51), OM (5.96%)
Rincón Chico, Orizaba, Veracruz	18°50′-97°05′	1,191	FW/2019-20	RH, MAS (pH 5.85), OM (5.9%)
CEIXTA, Tlapacoyan, Veracruz	20°02′-97°05′	88	FW/2019-20	RH, MAS (pH 5.18), OM (1.39%)
Rincón Grande, Orizaba, Veracruz	18°51′-97°06′	1,248	WS/2020	I, MAS (pH 6.51), OM (5.96%)

Note: CECECH = Central chiapas experiment station. CEIXTA = Ixtacuaco experiment station. FW = Fall-winter growing cycle. WS = Winter-spring growing cycle. RH = Residual soil moisture. I = Full irrigation. HAS = Highly acidic soil. MAS = Moderately acidic soil. OM = Organic matter content.

Table 2: Reaction of 14 black bean genotypes to the incidence of diseases in five environments of Veracruz and Chiapas, Mexico.

Genotype	WB1	Rust 2	BGYMV 3	BGYMV 4	BGYMV 5	BGYMV average
Papaloapan/SEN 46-2-6	3.33	3.67	3.67	4.67	3.67	4.00bcde
Papaloapan/SEN 46-3-2	2.00	4.00	4.00	5.33*	3.67	4.33bcd
Papaloapan/SEN 46-7-7	4.33	4.00	2.00	1.33	3.00	2.11gh
Papaloapan/SEN 46-7-10	4.33	3.67	2.67	3.00	4.33	3.33cdef
Papaloapan/SEN 46-7-12	4.33	3.67	3.00	3.33	4.33	3.56bcdef
Negro Citlali/XRAV-187-3-1-5	5.67*	2.33	3.00	2.00	4.00	3.00efg
Negro Citlali/XRAV-187-3-1-6	5.33*	3.00	1.67	2.00	1.33	1.67h
Negro Citlali/XRAV-187-3-1-8	4.67*	4.67*	3.33	2.33	4.67	3.44cdef
Jamapa Plus/XRAV-187-3-1-2	3.33	2.67	3.33	3.33	5.00	3.89bcde
Jamapa Plus/XRAV-187-3-4-1	2.00	2.33	5.00*	6.33*	6.67*	6.00a
Jamapa Plus/XRAV-187-3-4-4	3.00	3.33	3.00	2.33	4.33	3.22defg
Negro Medellín (RC)	4.33	5.67*	4.00	4.67	5.33	4.67b
Negro Jamapa (RC)	6.00*	5.00*	3.67	5.00	4.67	4.44bc
Verdín (RC)	3.00	5.33*	2.33	2.33	3.00	2.56fgh
Mean	3.97	3.81	3.19 b	3.43 b	4.14 a	3.59
ANVA = Analysis of variance	**	**	**	**	**	**
CV (%) = coefficient of variation	22.11	23.78	14.94	21.15	13.82	16.73
LSD (0.05)	1.476	1.521	0.800	1.217	0.961	1.134
Correlation (r) disease vs GY	-0.81**	-0.61*	-0.56*	-0.76**	-0.55*	-0.699**

Note: RC = Regional control. GY = Grain yield. WB = Web blight. BGYMV = Bean golden yellow mosaic. 1 = Rincón Grande, Orizaba, Ver., FW 2019-20, residual soil moisture. 2 = Rincón Chico, Orizaba, Ver., WS 2020, irrigation. 3 = Villa Corzo, Chis., FW 2019-20, residual soil moisture. 4 = CECECH, Ocozocoautla, Chis., FW 2019-20, residual soil moisture. 5 = El Gavilán, Ocozocoautla, Chis., FW 2019-20, residual soil moisture. The registered rating values correspond to the general scales from 1 to 9, to evaluate the reaction of bean germplasm to fungal and viral diseases (van Schoonhoven and Pastor-Corrales, 1987). *P≤0.05, **P≤0.01. ns = non-significant correlation. Incidence average of bean golden yellow mosaic with the same letters in the column of BGYMV average of genotypes are statistically similar according to the Least Significant Difference (LSD, 0.05).

Fig 2: Incidence of rust in some genotypes from stage R5, in Rincón Grande site during the 2020 winter-spring growing cycle.

Fig 3: Incidence of bean golden yellow mosaic virus in some genotypes (right side of the photograph) in El Gavilán, Ocozocoautla, Chiapas, during the 2019-20 fall-winter growing cycle.

Regarding the reaction of the genotypes to the incidence of bean golden yellow mosaic, Table 2 and Fig 3 shows that, in the three evaluation environments, the Jamapa Plus/ XRAV-187-3-4-1 line presented the greatest damage by this disease, in which an observed average incidence score of 6.0 was significantly higher than the rest of the genotypes. For its part, the Negro Citlali/XRAV-187-3-1-6, Negro Papaloapan/SEN 46-7-7, Negro Citlali/XRAV-187-3-1-5, Jamapa Plus/XRAV-187-3-4-4 lines and the Verdín variety showed resistance to this disease, with average incidence ratings between 1.67 and 3.22. Meanwhile, Negro Medellín and Negro Jamapa varieties, together with the Papaloapan/ SEN 46-2-6 and Papaloapan/SEN 46-3-2 lines, had an intermediate reaction (van Schoonhoven y Pastor-Corrales, 1987); this last line exhibited significant damage by bean golden yellow mosaic in E4 (rating of 5.33*). The resistance to bean golden yellow mosaic of Negro Citlali/XRAV-187-3-1-6, Negro Citlali/XRAV-187-3-1-5 and Verdín is because their plants possess the molecular marker SR 2, linked to the *bgm-1* gene, which confers genetic resistance to BGYMV (Urrea *et al*., 1996). In the case of Negro Papaloapan/SEN 46-7-7 and Jamapa Plus/XRAV-187-3-4-4, which do not have the *bgm-1* gene (Anaya-López *et al*., 2018), their low ratings to the reaction to this viral disease may be these lines contain other resistance genes or mechanisms that contributed to a stable resistance response throughout the evaluation environments. This is possible since their parents, 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 highest QTL for resistance to BGYMV (Anaya-López *et al*., 2018).

Grain yield also varied significantly between environments and genotypes, as well as in the interaction of both factors ($P \leq 0.01$). Table 3 shows that the highest average yield was obtained in E5, due in large part to the adequate humidity conditions (total rainfall of 374.1 mm) and temperature (average 17.8°C) during the growing cycle and because the bean plants grew in a soil rich in organic matter (5.90%), with a moderately acidic pH (5.85). In contrast, in E7, even though the bean crop had irrigation and developed in a soil rich in organic matter (5.96%) with a moderately acidic pH (6.51), the incidence of rust from the pre-flowering stage, significantly reduced bean production (Table 2). In turn, the lowest average yields were obtained in E4 and E2, respectively (Table 3). This was mainly due to two factors: 1) the soil in both test sites is highly acidic (pH of 4.26 and 4.79, respectively), which limits the availability of nutrients for the plants and 2) the early incidence of bean golden yellow mosaic that significantly affected bean yield (Table 2). In E6, with residual moisture a low average yield was also obtained, mainly due to low moisture availability during the reproductive phase of the crop, since of the 290 mm of rainfall during the crop cycle, only 37.1 mm fell from the R6 (flowering) to R9 (ripening) stages, an insufficient amount for adequate pod formation and filling.

In the AMMI analysis, highly significant variability ($P \leq 0.01$) was detected in the first four main components, which accumulated 95.4% in explaining the variance. Of these, the first three were the most important in the representation of the genotype-environment interaction, since they explained 84.2% of the sum of squares, which is considered satisfactory (Pereira *et al*., 2009). The test environments showed less dispersion than the genotypes, which indicates that the environmental variability was less than the genetic differences of the black bean germplasm included in this study. E1 was the environment

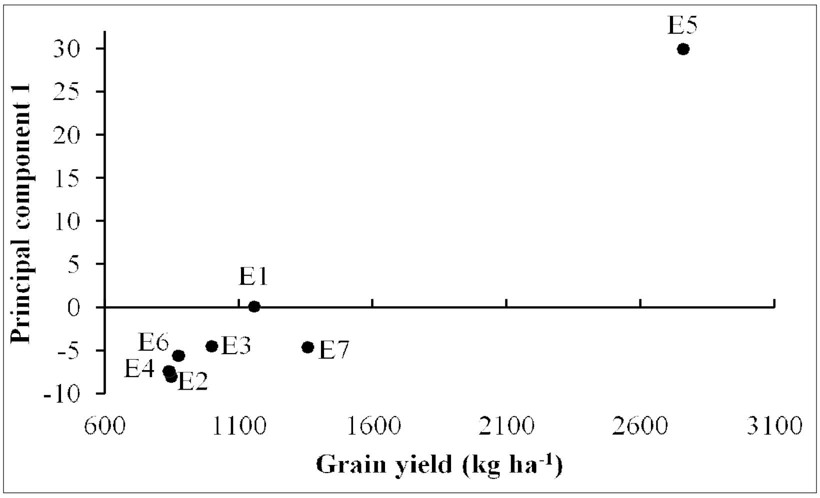

Fig 4: Main effects and observed interaction for seven test environments. E1 = Rincón Grande, Orizaba, Ver., FW 2019-20, residual soil moisture; E2 = Villa Corzo, Chis., FW 2019-20, residual soil moisture, highly acidic soil; E3 = CECECH, Ocozocoautla, Chis., FW 2019-20, residual soil moisture; E4 = El Gavilán, Ocozocoautla, Chis., FW 2019-20, residual moisture, highly acidic soil; E5 = Rincón Chico, Orizaba, Ver., AW 2019-20, residual moisture; E6 = CEIXTA, Tlapacoyan, Ver., FW 2019-20, residual humidity, terminal drought; E7 = Rincón Grande, Orizaba, Ver., WS 2020, full irrigation.

Table 3: Average performance of genotypes, environments and values of significant principal components.

Type	Genotype/Environment	GY (kg ha^{-1})	PC1	PC2	PC3
G1	Papaloapan/SEN 46-2-6	1252.90	-0.8895	8.867	3.9087
G2	Papaloapan/SEN 46-3-2	1298.90	4.1146	2.6871	-12.4977
G3	Papaloapan/SEN 46-7-7	1328.62	-5.8652	-5.461	-1.9598
G4	Papaloapan/SEN 46-7-10	1235.48	-7.6138	-0.1708	5.8567
G5	Papaloapan/SEN 46-7-12	1260.95	-2.1992	4.0677	-4.0778
G6	Negro Citlali/XRAV-187-3-1-5	1126.48	-4.3733	-7.8384	10.9126
G7	Negro Citlali/XRAV-187-3-1-6	1273.95	12.4871	-19.1641	-1.9414
G8	Negro Citlali/XRAV-187-3-1-8	1201.95	-5.721	-2.731	-1.7749
G9	Jamapa Plus/XRAV-187-3-1-2	1379.38	-0.1531	3.6491	12.9991
G10	Jamapa Plus/XRAV-187-3-4-1	1328.90	15.9307	11.0641	-0.7722
G11	Jamapa Plus/XRAV-187-3-4-4	1542.24	9.6827	3.2871	7.3939
G12	Negro Medellín (RC)	1086.33	-7.0415	3.8779	-6.8976
G13	Negro Jamapa (RC)	1021.29	-17.1202	-0.0126	-5.1257
G14	Verdín (RC)	1326.57	8.7618	-2.1219	-6.0241
E1	Rincón Grande, Orizaba, Ver., FW 2019-20, RM, MAS	1158.05	0.1236	20.3497	-2.2614
E2	Villa Corzo, Chis., FW 2019-20, RM, HAS	846.76	-8.072	-6.3058	-2.5438
E3	CECECH, Ocozocoautla, Chis., FW 2019-20, RM, MAS	998.62	-4.4311	-13.2178	8.132
E4	El Gavilán, Ocozocoautla, Chis., FW 2019-20, RM, HAS	838.43	-7.3507	-5.9757	-4.6428
E5	Rincón Chico, Orizaba, Ver., FW 2019-20, RM, MAS	2760.02	29.9669	-3.7718	-0.8074
E6	CEIXTA, Tlapacoyan, Ver., FW 2019-20, RM, MAS, TD	874.38	-5.6072	1.6175	-16.033
E7	Rincón Grande, Orizaba, Ver., WS 2020, I, MAS	1355.71	-4.6295	7.3038	18.1563
	Mean	1261.71			

Note: RC = Regional control. PC = Principal Component. G = Genotype. E = Environment. CECECH = Central chiapas experiment Station. CEIXTA = Ixtacuaco experiment station. FW = Fall-winter cycle. WS = Winter-spring cycle. RM = Residual soil moisture condition. I = Irrigation, MAS = Moderately acidic soil. HAS = Highly Acidic Soil, TD = Terminal drought.

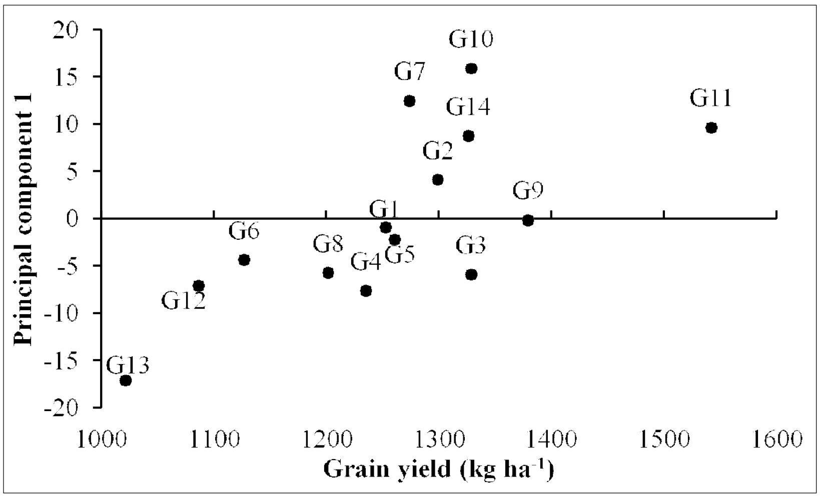

Fig 5: Main effects and interaction observed for the yield of 14 black bean genotypes. G1 = Papaloapan/SEN 46-2-6; G2 = Papaloapan/SEN 46-3-2; G3 = Papaloapan/SEN 46-7-7; G4 = Papaloapan/SEN 46-7-10; G5 = Papaloapan/SEN 46-7-12; G6 = Citlali Black/XRAV-187-3-1-5; G7 = Citlali Black/XRAV-187-3-1-6; G8 = Citlali Black/XRAV-187-3-1-8; G9 = Jamapa Plus/XRAV-187-3-1-2; G10 = Jamapa Plus/XRAV-187-3-4-1; G11 = Jamapa Plus/XRAV-187-3-4-4; G12 = Black Medellin; G13 = Black Jamapa; G14 = Verdín.

that showed the least interaction with the genotypes (PC1=0.1236), but low average yield, lower than the general mean (Table 3 and Fig 4), due to the negative effect on bean production caused by web blight. E3 and E7, also showed reduced interaction (PC1= -4.4311 and -4.6295, respectively) and low average yields (in E3 it was lower than the general mean) (Table 3 and Fig 4), mainly due to the significant damage caused by bean golden yellow mosaic and rust, respectively.

These three environments (E1, E3 and E7) with low PC1 values can be used to select opaque black bean genotypes, stable in their yield and with resistance to the indicated diseases for the central zone of the states of Chiapas and Veracruz and with potential adaptation to other areas with similar environmental conditions (López *et al*., 2015). On the other hand, in E5 (environment with the highest average yield observed), the highest interaction between the environment and the genotypes was observed (PC1= 29.9669) (Table 3 and Fig 4). This is attributed to very noticeable differences in the productive potential of this particular test site (yields that varied from 2021 to 3315 kg ha^{-1}) and the excellent adaptation of the genotypes. This location site has adequate environmental conditions (humidity, temperature and type of soil) that allowed excellent growth and development of the bean crop, as previously indicated. According to Acosta *et al*. (2004), environments that show high average yield and high interaction with the genotypes may be suitable for bean production if a genetic material with specific adaptation to these environments is available. In the three remaining environments, although they had a relatively low interaction with the genotypes, their average yield was much lower than the mean (Table 3 and Fig 4). Environment E6 can be used to select black bean materials tolerant to terminal drought (Tosquy *et al*., 2014), while environments E2 and E4 can be used to identify genotypes resistant to bean golden yellow mosaic and with adaptation to acidic soils, which are two of the main problems that affect bean production in the state of Chiapas (Villar *et al*., 2003).

In relation to the genotypes, two groups stood out: one made up of materials that had very low interaction with the environment including the Jamapa Plus/XRAV-187-3-1-2 (G9) line, which besides having obtained a significantly outstanding average yield of environments (Table 3), showed the lowest interaction with a PC1= -0.1531 (Table 3 and Fig 2). The same can be said for the Papaloapan/SEN 46-2-6 (G1) and Papaloapan/SEN 46-7-12 (G5) lines, which also had PC1 values-close to zero, but their average yield was lower (Table 3 and Fig 5). The genotypes that are close to the axis of the ordinates are considered to display a stable performance (Carbonell *et al*., 2004) and could be used for breeding both, recombinant lines and black bean cultivars with wide adaptation (López *et al*., 2011). Genotypes that show high and stable yields are ideal because they allow to increase average yield, while those that show low stability and low yield are not desirable (Ferreira *et al*., 2006). In this context, the Jamapa Plus/XRAV-187-3-1-2 line exhibited an ideal response throughout the test environments.

Conclusion

Two opaque black bean lines were identified that stood out for their high average yield, resistance to web blight and rust and low incidence of bean golden yellow mosaic under field conditions. The Jamapa Plus/XRAV-187-3-1-2 line, which showed the greatest stability (much higher than that of the three check varieties) and wide adaptation to the tropical and subtropical environments of evaluation. The Jamapa Plus/ XRAV-187-3-4-4 line was the most productive through the test locations and showed adaptation to very specific environmental conditions. The use of this line should be considered for those environments in which the line obtained the highest seed yields (adequate soil and moisture conditions, as well as the presence of fungal diseases) found in the central mountainous area of Veracruz and acid soil and incidence of bean golden yellow mosaic in central Chiapas.

Conflict of interest: None.

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