Article

Adaptation of black bean genotypes to different environments of Veracruz and Chiapas

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Abstract

In the present investigation, the main additive effects and multiplicative interaction (AMMI) model was used to determine the yield and stability of 12 lines and two varieties of opaque black beans, evaluated during 2016 and 2017, in 10 environments of Veracruz and Chiapas, Mexico. The trial was established in experimental design random blocks with three repetitions and plots of three rows of 5 m in length. The grain yield was quantified, which was analyzed individually by environment and combined (environments-genotypes) of the 10 test environments, stability parameters were also estimated with the AMMI model. The Experimental Field Ixtacuaco and Rincon Grande, Veracruz, in autumn-winter 2016-2017 under residual humidity, were the environments that combined low interaction and high productivity, making them ideal for identifying genotypes with high and stable performance. Venustiano Carranza, Chiapas, in autumn-winter of 2016-2017, El Rubi, Veracrus, in winter-spring of 2017 with irrigation and New Mexico, Chiapas, in summer of 2016, in whitewashed acid soil, were the environments that more interacted with genotypes. The Jamapa Plus/XRAV-187-3-1-8 line showed the least interaction with the environment (much higher than that shown by the Negro Comapa and Negro Grijalva varieties), as well as high average yield (1 437.3 kg ha^{-1}), while Jamapa Plus/XRAV-187-3-1-2, was the most profitable line (1 504.3 kg ha^{-1}), but its adaptation was specific, mainly in environments with edaphic acid stress in the center from Chiapas and by terminal drought in the center of Veracruz.

Keywords: *Phaseolus vulgaris* L., genotype-environment, interaction, improved lines.

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Introduction

In Veracruz and Chiapas, Mexico, during 2016, 150 784 hectares of opaque black grain beans were sown, tropical type (SIAP, 2018), which is the one with the highest commercial demand in the southeast region of Mexico, where 37.3 is produced % of this kind of beans in the country (Rodríguez *et al*., 2010; FIRA, 2016). The average yield in both entities is low (<650 kg ha^{-1}) (SIAP, 2018), because the crop is affected by biotic and abiotic factors.

In the former, the incidence of diseases such as the golden yellow bean mosaic (BGYMV), the common bean mosaic (BCMV), rust [*Uromyces appendiculatus* var. *appendiculatus* (Pers.) Unger] and the angular spot [*Pseudocercospora griseola* (Sacc.) Ferraris] (López *et al*., 2006; Tosquy *et al*., 2012). While, in the abiotic, the most important are: the occurrence of intra-summer drought (which commonly occurs from July 20 to August 20), in the temporary plantings of the summer cycle and terminal drought, which frequently It occurs after the flowering of the crop, when the beans are established in conditions of residual humidity, in the autumn-winter cycle (Tosquy *et al*., 2017), as well as the planting of beans in low fertility soils, acidic and with high saturation of aluminum (Villar *et al*., 2003; Tosquy *et al*., 2008).

To contribute to solving the indicated problem, in the Cotaxtla Experimental Field Bean Improvement Program (CECOT) of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), lines of early and advanced generations of opaque black beans in nurseries are evaluated of adaptation and in regional tests of yield, that are conducted in different locations, humidity conditions and agricultural crop cycles, in the southeast of Mexico, in such a way, that it allows to identify the most outstanding ones by their performance, stability and adaptability and with agronomic characteristics superior to those of the varieties currently used (López *et al*., 2012).

To determine the stability of genotype performance, in the CECOT Bean Improvement Program, the univariate model proposed by Eberhart and Russell (1966) has been used, who propose as stability parameters, the regression coefficient (Bi) and the regression deviation (S^2di), so a variety is considered stable, when Bi= 1 and S^2di= 0, while other value considerations for these parameters indicate that genotypes are unstable.

In recent years, the multivariate AMMI (additive main effects and multiplicative interaction) model described by Crossa *et al*. (1990), because it is more suitable for estimating stability, because it allows describing and interpreting the effects of IGA (Gauch Jr. and Furnas, 1991; Brancourt-Hulmel and Lecomte, 2003), in addition to being more effective for characterize the response of genotypes in environments (Williams *et al*., 2010; Vargas *et al*., 2016). The results can be plotted in a double entry biplot (CP1 *vs* performance biplot), where both the main effects, as well as the interaction effects, for genotypes and environments are placed, which facilitates the interpretation of the IGA (Vallejo, 2005; López *et al*., 2015). The objective of this research work was to identify elite lines that exceed in yield and adaptation to different production environments, to two varieties that are grown in the states of Veracruz and Chiapas.

Materials and methods

The uniform trial included 12 elite lines selected for their performance, adaptation or tolerance to one or more of the limiting factors: acid soil, drought and diseases (Garrido *et al*., 2017; Ibarra *et al*., 2017), which were generated by the INIFAP National Bean Program (four from the Papaloapan/SEN-46 cross, five from the Citlali/XRAV-187-3 black cross and three from Jamapa Plus/XRAV-187-3). The Negro Grijalva and Negro Comapa varieties, released by INIFAP for tropical areas of southeastern Mexico, were used as witnesses due to their high yield potential, wide adaptation and disease tolerance (Villar *et al*., 2009; López *et al*., 2012).

The trial was established in three environments in the center of the state of Chiapas and seven environments in the state of Veracruz (four in the central zone, two in the southern zone and one in the north). The location of the experimental sites, the planting cycle and the environmental condition in which the test was conducted is shown in Table 1.

Table 1. Location and characteristics of experimental sites where the regional uniform performance test was conducted in Veracruz and Chiapas.

Location	Municipality/state	Cycle/year	Environmental condition	Location (NL and WL)	Altitude (m)
Nuevo Mexico	Villaflores, Chis.	S / 2016	T- Acid soil (pH>5.6) -CD	16° 27’ and 93° 26’	660
Nuevo Mexico	Villaflores, Chis.	S / 2016	T- Acid soil (pH<4.4)	16° 27’ and 93° 26’	660
Carranza	Ocozocoautla, Chis.	AW / 2016-17	Residual humidity	16° 20’ and 92° 35’	597
Rincon Gde.	Orizaba, Ver.	AW / 2016-17	Residual humidity	18° 51’ and 97° 06’	1 248
El Rubi	Medellín, Ver.	AW / 2016-17	Residual humidity	18° 55’ and 96° 11’	22
ITA-JRC	Rodríguez Clara, Ver.	AW / 2016-17	HR- acid soil (pH >6.1) -CD	18° 01’ and 95° 24’	133
ITA-JRC	Rodríguez Clara, Ver.	AW / 2016-17	HR- acid soil (pH <4.7)	18° 01’ and 95° 24’	133
CEIXTA	Tlapacoyan, Ver.	AW / 2016-17	Residual humidity	20° 02’ and 97º 05’	88
El Rubi	Medellín, Ver.	WS / 2017	Irrigation during the cycle	18° 55’ and 96° 11’	22
El Rubi	Medellín, Ver.	WS / 2017	Terminal drought	18° 55’ and 96° 11’	22

ITA-JRC= Agricultural Technology Institute of Juan Rodriguez Clara. CEIXTA= Experimental Field Ixtacuaco. S= summer cycle. AW= autumn-winter cycle. WS= winter-spring cycle. T= temporary. HR= residual humidity. CD= with dolomite application.

The genotypes were sown at a density of 250 000 plants ha^{-1}, in experimental design randomized complete blocks with three replications and plots of three rows of 5 m in length, where the useful plot corresponded to the complete central groove. All genotypes are of habit of indeterminate growth, type II, of bushy and erect plants (Singh, 1982).

In one of the two trials of the New Mexico city, Chis., established in the summer cycle of 2016 and another of the Technological Institute of Juan Rodríguez Clara (ITA-JRC), Ver., in autumn-winter of 2016-17, before sowing 2 and 2.5 t ha^{-1} of dolomite lime were applied to the soil, respectively, to reach a pH that is within the optimum range of 5.5 to 7.5 and thus obtain an adequate development of the bean plants (Arias *et al*., 2007; Ruiz *et al*., 2013), the other two trials established in both locations were conducted under natural conditions of acid soil stress.

In El Rubi, Veracruz, in winter-spring of 2017, one trial was conducted with irrigation throughout the bean phenological cycle and the other with irrigation suspension, from the reproductive stage of the crop (terminal drought). It should be noted that during the conduct of the field trials there was no incidence of diseases that will affect bean yield, which was estimated in kilograms per hectare at 14% humidity.

The grain yield data were analyzed individually and in combination (genotype environments) of the 10 test environments. In cases where significance was detected, for the separation of averages the test was applied based on the significant minimum difference (DMS, α= 0.05). Likewise, the main additive effects and multiplicative interaction (AMMI) model was used to classify the environments and identify outstanding genotypes for their grain yield and less interaction with the environment (Gauch and Zobel, 1996).

For the analysis of variance and stability parameters, the SAS computer program (SAS Institute, 1999) was used and in the development of the AMMI analysis the recommendations of Vargas and Crossa (2000) were followed.

Results and discussion

Grain yield

According to the combined analysis, the performance varied significantly ($p\leq 0.01$) between environments, genotypes and in the interaction of both factors. Table 2 shows that, in Carranza, Chiapas, autumn-winter cycle of 2016-2017, under residual humidity conditions (A3), the highest average yield was obtained, which was significantly higher than the rest of the environments.

Table 2. Grain yield (kg ha^{-1}) of black bean genotypes evaluated in 10 environments of Veracruz and Chiapas, Mexico. Summer cycles of 2016, autumn-winter of 2016-2017 and winter-spring of 2017.

T	Genotype	Test environments				
		A1	A2	A3	A4	A5
G1	Papaloapan/SEN 46-3-7	2 116 *	1 120	1 379	2 097 *	1 367
G2	Papaloapan/SEN 46-6-6	1 403	1 004	1 449	1 952 *	1 097
G3	Papaloapan/SEN 46-7-7	1 973 *	560	1 538	1 693	1 518
G4	Papaloapan/SEN 46-7-11	1 181	848	2 357 *	1 980 *	1 713 *
G5	N Citlali/XRAV-187-3-1-6	1 905	1 007	2 096 *	1 238	1 580 *
G6	N Citlali/XRAV-187-3-1-8	1 655	1 068	2 409 *	1 298	1 742 *
G7	N Citlali/XRAV-187-3-14-6	1 748	1 068	1 872	1 720 *	1 260
G8	N Citlali/XRAV-187-3-14-7	1 401	568	2 420 *	1 438	1 548 *
G9	N Citlali/XRAV-187-3-16-7	1 343	1 335 *	1 378	1 368	1 368
G10	Jamapa Plus/XRAV-187-3-1-8	1 615	1 231	2 586 *	1 447	1 460

T	Genotype	Test environments					
		A1	A2	A3	A4	A5	
G11	Jamapa Plus/XRAV-187-3-1-2	2 276 *	1 304 *	1 692	1 505	1 660 *	
G12	Jamapa PlusX/RAV-187-3-4-4	1 144	1 071	2 159 *	1 563	1 887 *	
G13	Negro Comapa	1 876	1 484 *	2 387 *	1 480	1 270	
G14	Negro Grijalva	1 863	1 324 *	2 038	1 469	1 450	
	Average	1 678 b	1 071 c	1 983 a	1 589 b	1 494 b	
	ANVA	**	**	**	*	**	
	CV (%)	12.52	13.67	15.10	19.60	14.35	
	DMS (0.05)	352.8	245.7	502.7	522.8	360	
		A6	A7	A8	A9	A10	Average
G1	Papaloapan/SEN 46-3-7	598	482	1 755 *	1 328	1 094	1 333.5 abcde
G2	Papaloapan/SEN 46-6-6	693	505	1 645 *	1 146	729	1 162.2 e
G3	Papaloapan/SEN 46-7-7	653	394	1 603	1 276	820	1 202.8 de
G4	Papaloapan/SEN 46-7-11	582	396	1 609	1 203	594	1 246.4 bcde
G5	N Citlali/XRAV-187-3-1-6	633	455	1 729 *	1 302	1 080	1 302.6 abcde
G6	N Citlali/XRAV-187-3-1-8	911 *	706 *	1 876 *	1 250	859	1 377.5 abcde
G7	N Citlali/XRAV-187-3-14-6	627	442	1 375	1 031	573	1 171.6 e
G8	N Citlali/XRAV-187-3-14-7	689	480	1 538	1 297	838	1221.7 cde
G9	N Citlali/XRAV-187-3-16-7	576	369	1 473	1 318	922	1 144.9 e
G10	Jamapa Plus/XRAV-187-3-1-8	603	481	1 775 *	1 974 *	1 203	1 437.3 abcd
G11	Jamapa Plus/XRAV-187-3-1-2	715	475	1 609	2 271 *	1 536 *	1 504.3 a
G12	Jamapa PlusX/RAV-187-3-4-4	767	576	1 759 *	1 703	963	1 359.3 abcde
G13	Negro Comapa	661	512	1 444	1 964 *	1 385 *	1 446.2 abc
G14	Negro Grijalva	639	459	1 724 *	2 307 *	1 437 *	1 471 ab
	Average	668 d	481 d	1 637 b	1 526 b	1 002 c	1 312.9
	ANVA	**	**	**	**	**	**
	CV (%)	11.08	11.77	8.75	20.04	16.29	16.36
	DMS (0.05)	124.2	94.9	240.3	513.4	274.1	238.7

T= treatment (genotype); G= genotype; A= environment; A1= New Mexico, Villaflores, Chiapas, with dolomite; A2= New Mexico, Villaflores, Chiapas, without dolomite; A3= Carranza, Ocozocoautla, Chiapas; A4= Rincón Grande, Orizaba, Veracruz; A5= El Rubi, Medellin, Veracruz; A6= Rodríguez Clara, Veracruz, with dolomite; A7= Rodríguez Clara, Veracruz, without dolomite; A8= CEIXTA, Tlapacoyan, Veracruz; A9= El Rubi, Medellin, Veracruz, irrigation; A10= El Rubi, Medellin, Veracruz, drought; *= statistically superior genotypes, according to the minimum significant difference (DMS, 0.05). Averages of environments and genotypes with the same letters in the row and column, respectively, are statistically similar according to the DMS test, 0.05.

The highest average yield obtained in this locality, was mainly due to the fact that the crop had adequate humidity during its development cycle (568 mm of rainfall in total), without occurrence of periods of terminal drought. In turn, in the environments of New Mexico, Chiapas, summer cycle 2016, under conditions of whitewashed acid soil (A1), CEIXTA, Veracruz (A8) and Rincón Grande, Veracruz (A4), both in autumn-winter of 2016-2017 with residual humidity, as well as in El Rubi, Veracruz, in winter-spring of 2017 under irrigation conditions (A9) and in autumn-winter of 2016-17 with residual humidity (A5), also high average yields were obtained, because in all cases, the humidity conditions for the development of the beans were adequate (more than 320 mm of water during the cycle, of which about 150 mm were provided through the application of irrigation or received for the rains that occurred during the reproductive stage of the crop). For an adequate development and yield of the bean crop, at least 300 mm of rainfall are well distributed during its phenological cycle, 50 to 90 mm being convenient, from flowering to pod filling (Acosta *et al*., 2009; Ruiz *et al*., 2013).

On the contrary, the lowest average yields were obtained at the Agricultural Technology Institute of Juan Rodríguez Clara (ITA-JRC), Veracruz, in autumn-winter 2016-17, in acid soil, with application of dolomite lime (A6) and without application of dolomite (A7) (Table 2). This was mainly due to the water stress suffered by bean plants during their phenological cycle, since in the experimental site where both trials were conducted, there was a rainfall of the sowing until the harvest of 150.4 mm, of which only 24.4 mm precipitated during the reproductive phase of the crop, specifically the stages of pod formation when filling them, which limited the development of genotypes in both soil acid conditions. The lack of moisture during flowering, the formation of pods and their filling, causes a significant decrease in grain yield, due to a reduction in the number of pods per plant and a poor filling of pods (Acosta *et al*., 2009).

The same table shows that; through the evaluation environments, Jamapa Plus/XRAV-187-3-1-2, was the most productive line, whose average grain yield was statistically similar to that of five other lines and the control varieties, Negro Comapa and Negro Grijalva This same line, together with Negro Citlali/XRAV-187-3-1-8, obtained a significantly outstanding grain yield in five of the 10 test environments. Negro Citlali/XRAV-187-3-1-8, ranked first in performance in the environments of CEIXTA, Veracruz, in autumn-winter 2016-17, as well as in the ITA-JRC, Veracruz, in the same agricultural cycle, in acid soil, with and without application of dolomite lime, where it was the one with the highest productive efficiency (Tosquy *et al*., 2018). Meanwhile, Jamapa Plus/XRAV-187-3-1-2 was located first in the environments of New Mexico, Chiapas, in summer 2016, in whitewashed acid soil, and in El Rubi, Veracruz, in winter-spring 2017, with irrigation suspension at the beginning of the reproductive stage of the crop, where it showed greater tolerance to terminal drought and productive efficiency (with irrigation and drought), than the Negro Comapa and Negro Grijalva varieties (Ibarra *et al*., 2018).

AMMI analysis

According to the AMMI analysis, highly significant variability was detected in the first five main components, which accumulated 96.1% in the explanation of the variance, of these five, the first three were the most important in the representation of the IGA, since they explained 81.9% of the sum of squares. According to Pereira *et al*. (2009), the first three main components of this analysis should explain more than 60%, to be considered sufficient and at least 70% satisfactory.

This model allowed us to identify three groups of relatively homogeneous and well-defined environments, based on their average performance and their interaction with genotypes (Williams *et al*., 2010). The first group included three environments from Veracruz: El CEIXTA (A8), Rincón Grande (A4) and El Rubi (A5), all of them are similar in crop cycle (AW 2016-17) and humidity condition (residual moisture with adequate distribution of rainfall). These environments combined high average grain yield, significantly higher than the general average of 1 312 kg ha^{-1} and low interaction with genotypes (CP 1= -6.4547, -7.9732 and -11.2433) (Table 3, Figure 1). These two characteristics, in the process of genetic improvement, make them ideal for identifying opaque black bean germplasm, with high and stable yield, for the northern areas and region of the High Mountains in the center of the state of Veracruz (López *et al*., 2015).

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

Type	Genotype/environment	Yield (kg ha^{-1})	CP1	CP2	CP3
G1	Papaloapan/SEN 46-3-7	1 333.5	8.6001	-20.7015	0.9565
G10	Jamapa Plus/XRAV-187-3-1-8	1 437.3	0.2246	16.4036	-2.3564
G11	Jamapa Plus/XRAV-187-3-1-2	1 504.3	22.3616	2.5865	4.6737
G12	Jamapa PlusX/RAV-187-3-4-4	1 359.3	-9.0003	7.534	-10.4285
G13	Negro Comapa (TR)	1 446.2	9.7237	12.5242	-2.7705
G14	Negro Grijalva (TR)	1 471	15.4341	10.831	-3.9939
G2	Papaloapan/SEN 46-6-6	1 162.2	-2.3531	-16.2314	-11.4931
G3	Papaloapan/SEN 46-7-7	1 202.8	1.0064	-13.0445	12.9939
G4	Papaloapan/SEN 46-7-11	1 246.4	-19.757	-0.7866	-7.2652
G5	N Citlali/XRAV-187-3-1-6	1 302.6	-0.4576	2.8631	13.2464
G6	N Citlali/XRAV-187-3-1-8	1 377.5	-12.615	5.0874	8.9055
G7	N Citlali/XRAV-187-3-14-6	1 171.6	-5.1128	-9.7054	1.7015
G8	N Citlali/XRAV-187-3-14-7	1 221.7	-13.7884	7.402	7.6905
G9	N Citlali/XRAV-187-3-16-7	1 144.9	5.7337	-4.7624	-11.8601
A1	Nuevo Mexico, Villaflores, Chis., S 2016, T, acid soil - CD	1 678.5	16.5182	-11.5001	22.2422
A10	El Rubi, Medellín, Ver., WS 2017, terminal drought	1 002.5	15.7745	6.2012	0.7924
A2	Nuevo Mexico, Villaflores, Chis., S 2016, T, acid soil	1 070.8	9.2583	0.7911	-15.364
A3	Carranza, Ocozocoautla, Chis., AW 2016-17, HR	1 982.8	-21.6850	24.4266	5.4789
A4	Rincón Grande, Orizaba, Ver., AW 2016-17, HR	1 589.2	-7.9732	-23.1999	-11.4617
A5	El Rubi, Medellín, Ver., AW 2016-17, HR	1 494.3	-11.2433	0.8056	4.2890
A6	ITA-JRC, Ver., AW 2016-17, HR, acid soil - CD	667.6	-7.0106	-5.2081	1.0571
A7	ITA-JRC, Ver., AW 2016-17, HR, acid soil	480.9	-6.8706	-4.7559	-0.312
A8	CEIXTA, Tlapacoyan, Ver., AW 2016-17, HR	1 636.7	-6.4547	-4.763	0.9338
A9	El Rubi, Medellin, Ver., WS 2017, irrigation	1 526.4	19.6864	17.2024	-7.6558
	Average	1 312.9			

CP= main component; G= genotype; A= environment; S= summer cycle; AW= autumn-winter cycle; WS= winter-spring cycle; T= temporary condition; HR= residual moisture condition; CD= with dolomite application; ITA-JRC= Agricultural Technology Institute of Juan Rodríguez Clara; CEIXTA= Experimental Field Ixtacuaco.

The second group included two environments in the ITA-JRC, Veracruz, similar in crop cycle (AW 2016-17) and humidity condition (residual moisture with terminal drought) and different in soil management: one under soil conditions acid, without application of lime dolomite (A7) and another with application of lime dolomite (A6); both environments also showed reduced interaction with genotypes (CP 1= -6.8706 and -7.0106, respectively), but low average yield, much lower than the general average (Table 3, Figure 1). This behavior observed in both environments, is mainly attributed to the severity of water stress suffered by genotypes, which commonly occurs in that beans producing area (Morales *et al*., 2015), which did not allow them to express their potential for performance and that the differences between the vast majority of them were minimal.

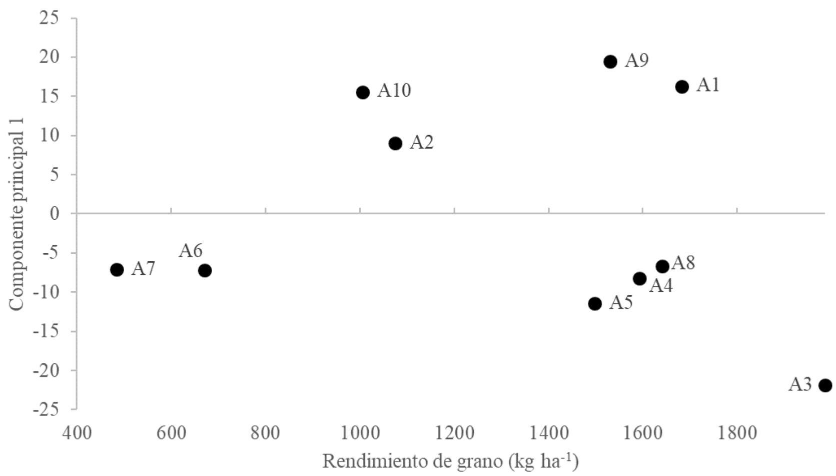

Figure 1. Main effects and interaction observed for 10 test environments. A1= New Mexico, Villaflores, Chiapas, with dolomite; A2= New Mexico, Villaflores, Chiapas, without dolomite; A3= Carranza, Ocozocoautla, Chiapas; A4= Rincón Grande, Orizaba, Veracruz; A5 = El Rubi, Medellín, Veracruz; A6= Rodríguez Clara, Veracruz, with dolomite; A7= Rodríguez Clara, Veracruz, without dolomite; A8= CEIXTA, Tlapacoyan, Veracruz; A9= El Rubi, Medellín, Veracruz, irrigation; A10= El Rubi, Medellín, Veracruz, drought.

The third group included three environments with adequate humidity during the crop cycle: Carranza, Chiapas, 2016-2017 AW cycle, with residual humidity (A3), El Rubi, Veracruz, 2017 WS cycle, with irrigation during the crop cycle (A9) and New Mexico, Chiapas, in the summer of 2016, under conditions of temporary and acid soil whitewashed with dolomite (A1), in which high average yield was observed and the highest interaction between the environment and genotypes (CP 1= -21.685, 19.6864 and 16.5182, respectively) (Table 3, Figure 1), this is mainly due to differences in the potential for performance and adaptation of genotypes in those evaluation environments, in which it was arranged of adequate humidity during crop development.

It should be noted that these three environments of high average performance, which are far from the axis of the ordinates (Figure 1) and that contributed more to the genotype-environment interaction, in certain cases, are suitable for bean production, if it has a genotype with specific adaptation to these environments (Acosta *et al*., 2012).

In relation to genotypes, two groups stood out: one formed with materials that showed very low interaction (close to zero) and therefore, a stable behavior (López *et al*., 2011), which includes the Jamapa line Plus/XRAV-187-3-1-8 (G10), which in addition to having obtained high average performance, showed the least interaction with the environment with a CP 1= 0.2246 (Table 3 and Figure 2), as well as at lines Negro Citlali/XRAV-187-3-1-6 (G5) and Papaloapan/SEN 46-7-7 (G3), which also showed reduced interaction with the environment (CP 1= -0.4576 and 1.0064, respectively), but their average yield was lower (Figure 2), these genotypes can be used in genetic improvement programs, for the generation of opaque black bean lines and varieties with wide adaptation. In the classification of genotypes for their stability, using the AMMI model, preferably those that are close to the axis of the ordinates should be selected, with CP 1 values equal to or close to zero (which are those that interact in a lesser degree with the environment) and show high grain yield (Vargas and Crossa 2000; Pereira *et al*., 2009).

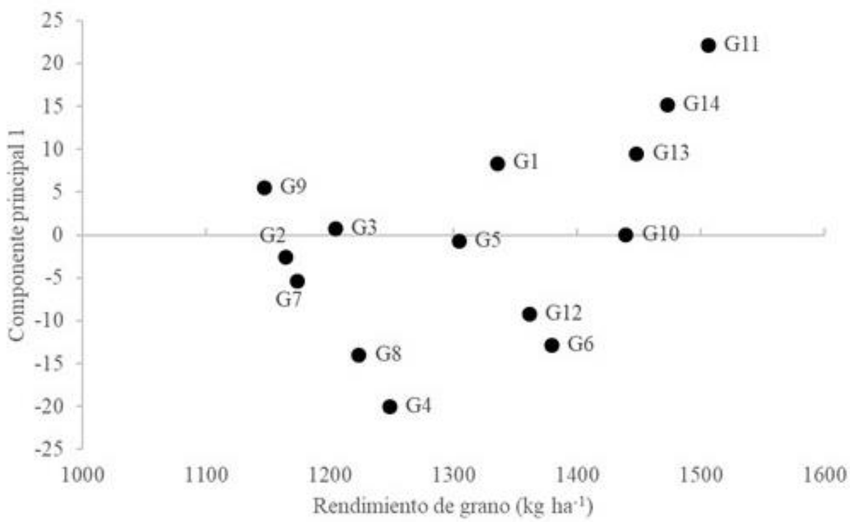

Figure 2. Main effects and interaction observed for the yield of 14 black bean genotypes.

The other group consisted of three genotypes that presented high average yield but high interaction with the environment; This group includes the Jamapa Plus/XRAV-187-3-1-2 (G11) line, which was the most productive and the one that interacted most with the environment (CP 1= 22.33616) (Table 3, Figure 2). This line showed specific adaptation in environments, with and without abiotic stresses: due to acid soil, in New Mexico, Chiapas, And terminal drought, in El Rubi, Veracruz, conditions in which it obtained significantly outstanding grain yields, so in the future, it may represent an option for planting in this type of soil in the center of the state of Chiapas and in autumn-winter, under conditions of residual humidity, in the state of Veracruz, where the occurrence of drought during the reproductive stage of the crop (Tosquy *et al*., 2014). The other two genotypes were: Negro Grijalva (G14) with CP 1= 15.4341 and Negro Comapa (G13) with CP 1= 9.7237 (Table 3, Figure 2), these two varieties showed specific adaptation to irrigation conditions and terminal drought in El Rubi, Veracruz, and edaphic acidity in New Mexico, Chiapas; Negro Comapa also showed a significant response in grain yield, to the application of dolomite lime, in the latter environment. Specific adaptation in a given area is also desirable, if the genotype shows stability over years in that area and high grain yield (Acosta *et al*., 2012).

These results indicate that, the stability of the performance of the genotypes evaluated is not a function of the genetic heritage from which they come, since in general, materials that were derived from the same cross, showed differences in their performance potential and adaptation to the environments test.

Conclusions

The AMMI analysis allowed to identify genotypes based on their level of interaction with the environment and grain yield. The Jamapa Plus/XRAV-187-3-1-8 (G10) line was the one that showed the greatest stability in the evaluation environments (superior to that observed by the Negro Comapa and Negro Grijalva varieties), as well as high yield of grain, and therefore will be included in the validation process with cooperating farmers in the states of Veracruz and Chiapas. Meanwhile, the Jamapa Plus/XRAV-187-3-1-2 (G11) line was the one with the highest average performance and its adaptation was specific, so its use in the environments in which it obtained yields of significantly outstanding grain, mainly under conditions of acid soil in the center of the state of Chiapas and terminal drought in the center of the state of Veracruz.

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