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Bean rust resistance and yield of black bean genotypes under field conditions

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ABSTRACT

Objective: To identify black beans lines resistant to bean rust under field conditions, which have similar or higher yield than three commercial varieties sown in Veracruz, Mexico.

Design/Methodology/Approach: The genotypes were evaluated using a completely randomized block design. The reaction of the genotypes to bean rust was qualified using a 1-9 incidence rate, while grain yield was estimated in kg ha^{-1}. An analysis of variance was carried out and the resulting means were divided using a 0.05 Least Significant Difference (LSD). Additionally, a correlation analysis between the incidence values of bean rust and the yield of the genotypes was carried out in each evaluation site.

Results: Nine lines were resistant to bean rust (incidence average: 1.78-3.33). Out of these lines, Jamapa Plus/XRAV-187-3-4-4 was the most productive line, with a 2,183.4 kg ha^{-1} average yield. This result is statistically similar to the results of the Jamapa Plus/XRAV-187-3-4-1 and Jamapa Plus/XRAV-187-3-1-2 lines and the Verdín variety. In addition, the results of Jamapa Plus/XRAV-187-3-4-4 are slightly higher than the results obtained by the rest of the genotypes.

Study Limitations/Implications: Although bean rust was recorded in three of the localities of the study area, the incidence degree and the stage when it was found were different. However, in all the cases, the infection degree was enough to evaluate the reactions of the genotypes to this disease.

Findings/Conclusions: Three bean rust-resistant lines were identified under field conditions. They had a significantly higher average yield than the Negro Jamapa and Negro Medellín varieties.

Keywords: *Phaseolus vulgaris* L., *Uromyces appendiculatus*, productivity.

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INTRODUCTION

There is a great physiological variation among the races of *Uromyces appendiculatus* var. *appendiculatus* (Pers.) in Mexico; this pathogen causes bean rust, which is one of the main fungal diseases of bean (*Phaseolus vulgaris* L.) crops [1]. All the bean production areas of the state of Veracruz have been impacted by this fungus, although it has a higher frequency incidence in the areas located at an altitude >800 m, with environmental temperature between 17 and 27 °C and a 90% relative humidity [2]. The yield of the Negro Jamapa and

other native varieties can be reduced by more than 40% when the bean rust appears before the flowering [3]. Mancozeb® and cooper oxychloride® are the main fungicides used to control bean rust [2]; they are usually applied in more than one occasion, increasing the production cost of the crop [4]. A more economical and environmentally friendly alternative is the use of improved bean rust-resistant varieties, which can be successfully adapted to the bean cultivation areas in Veracruz [5]. The Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) has developed several tropical black bean varieties, which have proven to be naturally resistant or tolerant to some *U. appendiculatus* physiological races, under field conditions [6,7]. However, in order to guarantee the identification of bean lines and to develop varieties which are resistant or tolerant to the pathogens, they must be inoculated with spores of the main *U. appendiculatus* races that impact commercial bean crops [5]. Therefore, in 2019, the reaction of 53 advanced bean lines and three opaque black beans varieties (the preferred crop in Veracruz) were evaluated under greenhouse conditions. These lines and varieties were subjected to an artificial inoculation with spores obtained from different bean production areas of the states of Veracruz and Chiapas. Eleven lines with high resistance [5] and good adaptation to the bean production areas of Veracruz [8] were selected for this study. The evaluations took place under field conditions, in three environments of Veracruz, in which bean rust is frequently reported. The objective of this study was to identify the lines with higher resistance to bean rust and which have a similar or higher yield than the three control varieties. Additionally, it should be possible to release these lines as commercial varieties.

MATERIALS AND METHODS

The genotypes were evaluated in Rincón Grande (18° 51’ N and 97° 06’ W, 1,248 m.a.s.l.), during the 2019-2020 autumn-winter (A-W) cycle and the 2020 winter-spring (W-S) cycle and in Rincón Chico (18° 50’ N and 97° 05’ W, 1,191 m.a.s.l.), during the 2019-2020 autumn-winter cycle. Both localities are part of the Orizaba Municipality, located in central Veracruz. Out of the 11 evaluated lines, 5 were a cross of the Negro Papaloapan/SEN 46, 3 were a cross of the Negro Citlali/XRAV-187-3, and 3 were a cross of the Jamapa Plus/XRAV-187-3. These crosses were developed by the Programa Nacional de Frijol y Garbanzo (Bean and Chickpea National Program) of the INIFAP, at the Campo Experimental Bajío in Celaya, Guanajuato. The Negro Medellín, Verdín, and Negro Jamapa varieties were used as control crops. The genotypes were sown in a density equivalent to 250,000 plants ha^{-1}, in a completely randomized block design, with three repetitions. Each experimental unit consisted of three 5-m long furrows, with a 0.80 m separation between them. In the A-W cycle, the experiment was conducted under residual humidity conditions, while six gravity irrigations were applied in the W-S cycle, at 10-15 days intervals.

During the bean pod filling stage, the reaction of some genotypes to the bean rust incidence was visually evaluated, using the 1-9 general scale proposed by the International Center for Tropical Agriculture [9]. This scale has different levels of reaction: 1-3 means that the plant is resistant (non-visible or very minor signs); 4-6 means that the plant has an intermediate reaction (visible symptoms that cause a limited economic damage); and 7-9 means that the plant is susceptible (severe to very severe symptoms that cause significant yield loses or the death of the plant). During the ripening stage, yield grain was calculated in kg ha^{-1}, with 14% humidity. The bean rust incidence and yield grain data were subjected to an individual and joint analysis of variance for the three evaluated environments. In order to divide the means, a test based on the Least Significant Difference was applied, with a 5% error probability (LSD, α=0.05). Additionally, correlation analyses were carried out to determine in which evaluated environments bean rust caused a significant grain yield damage.

RESULTS AND DISCUSSION

The bean rust incidence was significantly different (P≤0.05) between the evaluated environments. Only in Rincón Grande, a significant grain yield reduction was recorded during the 2020 W-S cycle; this reduction was caused by a greater and earlier incidence (Table 1) of this disease (from the beginning of the pre-flowering stage). During this stage the disease can cause a greater damage [1]. Fifteen days after the sowing (das), relative high humidity (>80%) and temperature (15.4-28 °C) conditions prevailed in the area for a 20-d period which resulted in a greater incidence [10]. Meanwhile, during the 2019-2020 A-W cycle, no significant grain yield reduction was recorded in Rincón Chico (Table 1), although bean rust had a statistical similar average than in the previous environment, because this disease only appeared during the bean pod filling stage. During the same agricultural cycle, in Rincón Grande, although bean rust appeared during the pre-flowering stage, the minor incidence of the disease did not cause a significant damage to bean yield (Table 1).

Bean rust incidence also had a significant variation (P≤0.01) between genotypes as well as in the three evaluated areas. Table 2 shows that most of the lines had very mild symptoms of the disease in all the environments; only Negro Citlali/XRAV-187-3-1-8 had an intermediate reaction, with significative bean rust damage, during the 2020 W-S cycle in Rincón Grande. Meanwhile, nine lines had a 1.78-3.33 bean rust incidence average, which means that they are resistant to this disease [9]. In previous studies carried out under greenhouse conditions, these lines had already shown a hypersensitive reaction to the inoculation with bean rust (*i.e.*, they only showed small chlorotic spots without sporulation [5]); consequently, they are highly resistant to this disease [11]. Meanwhile, the control varieties shown significant damages in two out of the three studied environments;

Table 1. Bean rust mean values per evaluated environment and its impact on bean yield.

Environment	Incidence (scale 1 - 9)	Correlation coefficient rust *vs.* yield
Rincón Grande, I-P 2020	3.81 a	r=−0.608 *
Rincón Chico, O-I 2019-20	3.31 ab	r=−0.289 ns
Rincón Grande, O-I 2019-20	2.88 b	r=−0.200 ns
DMS (0.05)	0.579	

Bean rust incidence mean values with the same letter in the environment (ambiente) column are not statistically different, according to the LSD (DMS) (α=0.05). *=Significant Correlation; ns=Non-Significant Correlation.

Table 2. Bean rust incidence mean values of 14 black beans genotypes, in three environments of the state of Veracruz (2019-2020 Autumn-Winter cycle and 2020 Winter-Spring cycle).

Genotype	Rincón Grande O-I 2019-20	Rincón Chico O-I 2019-20	Rincón Grande I-P 2020	Incidence average
Papaloapan/SEN 46-2-6	3.33	2.00	3.67	3.00 def
Papaloapan/SEN 46-3-2	3.33	4.67	4.00	4.00 bcd
Papaloapan/SEN 46-7-7	2.33	2.67	4.00	3.00 def
Papaloapan/SEN 46-7-10	2.33	3.67	3.67	3.22 cde
Papaloapan/SEN 46-7-12	3.00	2.33	3.67	3.00 def
Negro Citlali/XRAV-187-3-1-5	2.00	1.00	2.33	1.78 f
Negro Citlali/XRAV-187-3-1-6	1.00	1.33	3.00	1.78 f
Negro Citlali/XRAV-187-3-1-8	2.33	4.33	4.67 *	3.78 cd
Jamapa Plus/XRAV-187-3-1-2	2.67	3.00	2.67	2.78 def
Jamapa Plus/XRAV-187-3-4-1	2.00	1.67	2.33	2.00 ef
Jamapa Plus/XRAV-187-3-4-4	3.00	3.67	3.33	3.33 cd
Negro Medellín (TR)	3.33	7.00 *	5.67 *	5.33 a
Negro Jamapa (TR)	4.33 *	4.00	5.00 *	4.44 abc
Verdín (TR)	5.33 *	5.00	5.33 *	5.22 ab
DMS (0.05)	1.118	1.275	1.521	1.252

RC (TR)=Regional Control. A-W (O-I)=Autumn-Winter. W-S (I-P)=Winter-Spring. *=Bean rust incidence values were statistically higher in each evaluated environment, according to the LSD (DMS) (α=0.05). Bean rust incidence mean values with the same letter in the genotype column are not statistically different, according to the LSD (DMS) (α=0.05).

additionally, they also recorded the highest bean rust incidence mean values (Table 2). The susceptibility to bean rust of the Negro Jamapa, Negro Medellín, and Verdín varieties had been previously recorded [3,1,12].

Additionally, a grain yield statistical significance was detected (P≤0.01) between environments and genotypes. During the 2019-2020 A-W cycle, the highest mean yield was obtained in Rincón Chico (Table 3), because the crop developed under the appropriate humidity and temperature conditions [13] and bean rust appeared belatedly. Meanwhile, during the 2020 W-S cycle, the early bean rust incidence in Rincón Grande had a significant impact on grain production. An excessive rainfall (802.1 mm) in Rincón Grande resulted in the lowest grain yield during the 2019-2020 A-W cycle; 60.5% of the total rainfall was recorded during the first 30 das [9], causing a deficient development of the plants [13].

Jamapa Plus/XRAV-187-3-4-4 was the most productive line among the bean rust-resistant lines in the three evaluated environments (Table 3). The grain yield average of Jamapa Plus/XRAV-187-3-4-4 was statistically similar to the results obtained by Jamapa Plus/XRAV-187-3-4-1 and Jamapa Plus/XRAV-187-3-1-2, as well as by the Verdín variety; it was significatively higher than the rest of the genotypes (Table 3). Tosquy *et al.* (2019) reported that the Jamapa Plus/XRAV-187-3-4-4 and Jamapa Plus/XRAV-187-3-1-2 had a remarkably high productivity. Negro Jamapa and Negro Medellín recorded the lowest yield averages mainly as a consequence of the damages caused by bean rust.

Table 3. Bean rust incidence mean values of 14 black beans genotypes, in three environments of the state of Veracruz (2019-2020 Autumn-Winter cycle and 2020 Winter-Spring cycle).

Genotype	Rincón Grande O-I 2019-20 (kg ha^{-1})	Rincón Chico O-I 2019-20 (kg ha^{-1})	Rincón Grande I-P 2020 (kg ha^{-1})	Average (kg ha^{-1})
Papaloapan/SEN 46-2-6	1166.67	2718.67	1640.00*	1841.7 abcd
Papaloapan/SEN 46-3-2	1233.33	2933.33	1213.33	1793.3 bcd
Papaloapan/SEN 46-7-7	1222.00	2654.67	1266.67	1714.4 bcde
Papaloapan/SEN 46-7-10	1117.67	2503.33	1464.33*	1695.1 bcde
Papaloapan/SEN 46-7-12	1326.67*	2662.00	1246.33	1745.0 bcd
Negro Citlali/XRAV-187-3-1-5	789.00	2531.00	1433.33*	1584.4 de
Negro Citlali/XRAV-187-3-1-6	715.33	3227.67*	1206.67	1716.5 bcde
Negro Citlali/XRAV-187-3-1-8	1131.00	2528.33	1184.67	1614.6 cde
Jamapa Plus/XRAV-187-3-1-2	1388.67*	2827.00	1671.33*	1962.3 abc
Jamapa Plus/XRAV-187-3-4-1	1462.33*	3260.33*	1409.00*	2043.8 ab
Jamapa Plus/XRAV-187-3-4-4	1497.67*	3315.00*	1737.67*	2183.4 a
Negro Medellín (TR)	1069.00	2364.33	1122.33	1518.5 de
Negro Jamapa (TR)	849.00	2021.00	1180.00	1350.0 e
Verdín (TR)	1244.33*	3093.67*	1204.33	1847.44abcd
Promedio de ambiente	1158.05 c	2760.02 a	1355.71 b	1757.93
DMS (0.05)	261.65	367.38	378.78	375.78

RC (TR)=Regional Control. A-W (O-I)=Autumn-Winter. W-S (I-P)=Winter-Spring. *=Bean rust incidence values were statistically higher in each evaluated environment, according to the LSD (DMS) (α=0.05). Bean rust incidence mean values with the same letter in the genotype column are not statistically different, according to the LSD (DMS) (α=0.05).

CONCLUSIONS

The Jamapa Plus/XRAV-187-3-4-4, Jamapa Plus/XRAV-187-3-4-1, and Jamapa Plus/XRAV-187-3-1-2 lines showed resistance to the spore inoculation of different *U. appendiculatus* physiological races, found in the commercial crops of Veracruz and Chiapas, México. They also recorded a significantly higher grain yield average among these varieties than in the Negro Jamapa and Negro Medellín control varieties. Therefore, these three varieties can be released as commercial varieties in the short term.

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