Adaptation and Resistance to Diseases in Brazil of Putative Sources of Common Bean Resistance to White Mold

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Abstract

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Common bean breeding programs for white mold (WM) resistance are in their initial stages in Brazil. Sources of partial resistance to WM are available abroad but their performance in Brazil is unknown. In two greenhouse (straw test) and three field experiments conducted in three districts in the state of Minas Gerais, Brazil, we evaluated a total of 23 lines with putative WM resistance with the objective to select lines with resistance to WM and other diseases associated with high yield potential. Two field-resistant local lines, two susceptible local cultivars, and two susceptible international lines

were also included in the study. In the greenhouse, Cornell 605, A 195, and G122 were among the lines with the highest partial resistance to WM. In the field, these three lines were highly resistant to WM and had intermediate resistance or were resistant to anthracnose, angular leaf spot, rust, and Fusarium wilt. Cornell 605 and A 195 had high-yield potential but G122 yielded 47% less than the local lines under WM pressure. Our results suggest that Cornell 605 and A 195 are the most useful sources of resistance to WM for use in common bean breeding programs in Brazil.

Common bean (*Phaseolus vulgaris* L.) is the most important pulse in the world (1). Brazil ranks first in common bean production (2,832,000 metric tons during the growing season of 2012 to 2013), with average yield of 910 kg ha⁻¹. Brazil has five regions: northern, northeastern, midwestern, southeastern, and southern. The southern region produces 31% of the total common bean, southeastern produces 29%, and Midwestern produces 21%. In these three regions, common bean is produced in the fall-winter (21% of the total production), summer-spring (41%), and spring-fall seasons (38%) (3).

In the fall-winter season, when irrigation is required, the states of Minas Gerais (46%) and São Paulo (14%) in the southeastern region and Goiás (24%) in the midwestern region are the largest common bean producers (3). In this season, irrigation, heavy fertilizer application, and use of pesticides are among the factors that promote profuse growth of common bean plants. Thus, average yield in the fall-winter season in the southeastern and midwestern regions is 2,534 kg ha⁻¹ (3). However, environmental conditions are conducive to the development of white mold (WM), caused by *Sclerotinia sclerotiorum* (Lib.) de Bary. Cultivars used by farmers in this season are generally of the “carioca” class (beige with brown stripes), with semiprostrate or prostrate indeterminate growth habit (type III). Cultivars with prostrate growth habit have been shown to favor WM development in the field compared with type II or type I cultivars (11,32). Other frequent diseases in the fall-winter season are anthracnose (*Colletotrichum lindemuthianum* (Sacc. & Magnus) Briosi & Cavara), angular leaf spot (*Pseudocercospora griseola* (Sacc.) Crous & U. Braun), rust (*Uromyces appendiculatus* (Pers.) Link), and diseases caused by soilborne pathogens (18).

Two fungicide applications for WM control can double common bean yield (31). However, their high cost and potentially deleterious environmental and human effects have motivated the search for new options for WM management. In addition to fungicide applications, a combination of techniques helps control WM. Biological control, deep plowing, long-term rotations with nonhost crops, less irrigation

and nitrogen fertilization (19), lower plant population (31), and genetic resistance (11,19) are among the most commonly used techniques. Genetic resistance is a key component of WM management in common bean, because it is easier for farmers to adopt and is environmentally safe.

There is no known source of complete resistance to WM in common bean but genotypes with partial resistance that result in reduced disease are available. Reduced WM is conditioned by both avoidance and physiological mechanisms (14). Avoidance limits infection and reduces WM progress in the field. In this case, genotypes with erect and open plant structure, elevated pod set, and reduced lodging contribute to less WM damage (11,19). Physiological mechanisms include plant defense, which reduces the spread of *S. sclerotiorum* into plant tissues (23). Screening for WM resistance is performed in field, greenhouse, or laboratory conditions. In the field, both mechanisms of plant resistance can affect the results of screening tests. Laboratory and greenhouse screening methods are used to detect physiological mechanisms (14). In the greenhouse, the straw test is currently the most widely used method worldwide for detection of physiological resistance in common bean (19).

The search for sources of WM resistance in common bean has just begun in Brazil. In other countries, however, genotypes with partial resistance to WM have been identified (5,10,11,14,19,22). These genotypes might be useful for common bean breeding programs in Brazil. However, no information is available about adaptation and resistance to diseases of these genotypes in Brazil. We evaluated lines from the Bean White Mold Nursery (7,8), with the objective to select lines with resistance to WM and other diseases associated with high yield potential under Brazilian growing conditions.

Materials and Methods

The straw test. Two experiments were carried out to assess physiological resistance to an *S. sclerotiorum* isolate in common bean lines from the Bean White Mold Nursery (7,8). Seed from these lines were originally supplied by S. McCoy (University of Nebraska). The first experiment was established in July 2010 with 20 putative sources of WM resistance (Table 1) and the susceptible controls ‘Beryl’ (5) and ‘Orion’ (11). The second experiment was established in February 2012, with three additional putative sources of WM resistance and four Brazilian genotypes included in the experiment (Table 1). The Brazilian small-seeded Mesoamerican genotypes of the carioca class were lines CNFC 9500 and CNFC 10720 and cultivars

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'BRSMG Majestoso' and 'BRSMG Madrepérola'. The Brazilian lines exhibit type II, upright, short-vine plant habit and partial resistance to WM in the field, whereas the cultivars possess type III indeterminate growth habit and are among the genotypes most susceptible to WM (32).

Sclerotia were collected from mature common bean plants with WM symptoms in the district of Oratórios (20°24'14" S, 42°49'10" W), Zona da Mata region, state of Minas Gerais, Brazil. One sclerotium was randomly selected and surface disinfested in 70% ethanol for 1 min, followed by 1% sodium hypochlorite for 3 min. The sclerotium then was rinsed twice in sterile distilled water, transferred to a 9-cm-diameter petri dish containing 20 ml of potato dextrose agar (PDA; Acumedia; Neogen Corporation, Lansing, MI) and chloramphenicol at 100 mg liter⁻¹, and incubated at 23°C in the dark for myceliogenic germination. Six days later, a single hyphal tip was transferred to PDA and maintained at 23°C in the dark for 10 to 15 days. This isolate was coded as Ss-2.

In the 2010 experiment, 5-liter pots were filled with soil, sand, and cured manure (3:1:1). In the 2012 experiment, 3-liter pots were filled with the commercial substrate Tropstrato HT Hortaliças (Vida Verde, Mogi-Mirim, SP, Brazil) with pH 5.8 and prepared with pine bark, processed peat, vermiculite, superphosphate, and potassium nitrate (rates of these fertilizers were not available). Five seeds were sown per pot, and seedlings were thinned to three following emergence. A completely random design with three replicates was used. Each replicate was a pot. Temperature in the greenhouse was 15 to 26°C in the 2010 experiment and 18 to 29°C in the 2012 experiment. An irrigation system watered pots for 2 min every 2 h in the 2010 experiment and for 1 min every 1 h in the 2012 experiment. In addition to providing water, the irrigation system helped maintain relative humidity greater than 80%.

Twenty-three days after seedling emergence, the main stem of each plant was cut 2.5 cm above the fourth node. The cut stem was capped with one mycelial disc that was punched with a 1,000-μl Eppendorf tip according to Téran and Singh (29). At 7 and 14 days after inoculation (DAI), WM reaction was scored using a 1-to-9 scale, where 1 = no infection, 2 = infection occurred but invasion of the first internode <2 cm, 3 = invasion progressed >2 cm but did not reach the first node, 4 = invasion reached the first node but no further, 5 = invasion passed the first node but progressed <2 cm on the second internode, 6 = invasion of the second internode >2 cm but did not reach the second node, 7 = invasion reached the second node but no further, 8 = invasion passed the second node but progressed <2 cm on the third internode and no plant death, and 9 = invasion of the third internode >2 cm or plant death (25). In the 2012 experiment, the WM reaction at 7 and 14 DAI was also assessed using lesion length.

Field experiments. Three experiments were conducted during the fall-winter season in three districts of the Zona da Mata region, state of Minas Gerais, Brazil: Coimbra (experiment I), Oratórios (experiment II), and Viçosa (experiment III). Experiments I (20°49'45" S, 42°45'47" W) and III (20°45'28" S, 42°49'26" W) were carried out at the experimental stations of the Federal University of Viçosa at 717 and 657 m above sea level, respectively. Experiment II (20°24'14" S, 42°49'10" W) was carried out at the experimental station of the Minas Gerais Agricultural Research Institute (Epamig) at 486 m above sea level. According to Köppen's classification, the climate in the Zona da Mata region is Cwa (subtropical warm with dry winter). Soils in these areas are clayey dystrophic red-yellow Argisol (Ultisol) with 1% slope. All three sites have a history of WM disease in common bean. The soils were disc plowed to a depth of approximately 20 cm followed by heavy-disc harrowing twice. Seed were sown in 2010 on 22 April (experiment I), 19 May (experiment II), and 16 April (experiment III).

Except for Beryl, Cornell 603, NE1-06-12, NE1-07-12, NE2-06-8, and Roma II, which produced insufficient seed, the genotypes included in the greenhouse experiments were included in the field experiments (Table 2). A randomized block design with four replicates was used.

Each plot had two 2-m-long rows. A density of 15 seeds m⁻¹ was sown in rows 0.5 m apart. One row of BRSMG Madrepérola was planted as the external border of each experiment. Plots received dry fertilization of 28 kg of N, 43 kg of P, and 46 kg of K per hectare at sowing. Plants were hand thinned to 10 plants m⁻¹ at the V3 growth stage (one trifoliate leaf). At the V4 growth stage (third trifoliate leaf), urea at 200 kg ha⁻¹ was applied as a side dressing and a solution of sodium molybdate (Mo at 80 g ha⁻¹) was sprayed on the foliage to ensure lush vegetative growth of plants. Weeds were controlled with a mixture of the postemergence herbicide fomesafen at 250 g ha⁻¹ and fluzafop-p-butyl at 200 g ha⁻¹ (Robust microemulsion; Syngenta Proteção de Cultivos, Brazil). Control of pests, especially leafhopper (*Empoasca kraemeri* Ross & Moore, 1957), was made with the insecticide metamidophos at 0.4 liter ha⁻¹ (Tamaron 600SL; Proteção de Plantas, Brazil). Fungicide was not used. Irrigation was provided at a 2-day interval after sowing to promote good seedling emergence. From seedling emergence until flowering, irrigation complemented rainfall so that the soils received at least 40 mm of water once every week. From flowering until plant maturity, the soils received approximately 30 mm of water twice a week to favor disease development.

WM reaction was scored visually at maturity using a 1-to-9 scale based on combined incidence and severity (intensity) of infection, where 1 = no diseased plants, 2 = 1 to 20% diseased plants or 1 to 5% infected tissues, 3 = 20 to 30% diseased plants or 5 to 10%

Table 1. White mold reaction of common bean genotypes evaluated at 7 and 14 days after inoculation (DAI) using the greenhouse straw test in 2010 and 2012^a

Genotype ^b	2010 experiment		2012 experiment			
	Reaction score		Reaction score		Lesion length (cm)	
	7 DAI	14 DAI	7 DAI	14 DAI	7 DAI	14 DAI
A 195	4.2 (02)	4.7 (03)	3.3 (01)	3.3 (01)	2.8 (01)	2.9 (01)
11A-39	2.9 (01)	3.3 (01)	3.7 (03)	4.7 (05)	3.8 (03)	4.2 (06)
Cornell 603	4.5 (03)	4.6 (02)	4.1 (05)	4.4 (03)	4.1 (06)	4.2 (05)
G122	4.9 (04)	6.1 (10)	3.8 (04)	4.6 (04)	4.0 (05)	4.0 (04)
WM31	6.0 (14)	6.8 (14)	5.2 (08)	5.7 (06)	3.8 (04)	3.9 (03)
NE2-07-10	5.0 (06)	5.4 (04)	5.6 (12)	5.9 (08)	5.7 (11)	5.8 (08)
Ex Rico 23	5.7 (09)	5.8 (05)	5.7 (13)	6.2 (09)	5.3 (08)	5.6 (07)
37-2	4.9 (05)	5.9 (07)	5.6 (09)	6.3 (10)	5.8 (12)	7.5 (13)
Avalanche	5.9 (13)	6.0 (08)	5.6 (11)	5.8 (07)	6.0 (13)	6.3 (11)
29C-6	5.9 (11)	6.9 (15)	5.2 (07)	6.4 (14)	5.2 (07)	6.0 (10)
Tapia	5.0 (07)	5.8 (06)	4.8 (06)	6.3 (13)	6.0 (14)	8.6 (19)
38-4	5.9 (12)	6.5 (11)	5.6 (10)	6.3 (11)	5.7 (10)	7.8 (14)
B07104	6.5 (19)	7.0 (16)	6.0 (14)	6.3 (12)	6.2 (15)	6.4 (12)
P07863	6.4 (18)	6.8 (13)	7.1 (20)	7.3 (17)	7.9 (21)	7.9 (15)
Roma II	5.2 (08)	6.0 (09)	6.2 (17)	8.1 (22)	9.0 (24)	14.8 (26)
NE1-07-12	6.4 (17)	7.4 (17)	6.1 (15)	7.3 (18)	7.2 (18)	11.6 (22)
NE2-06-8	7.7 (21)	8.1 (21)	6.9 (19)	8.1 (21)	8.5 (23)	10.5 (21)
Beryl	5.7 (10)	6.8 (12)	7.7 (24)	8.9 (28)	11.9 (28)	18.7 (29)
NE1-06-12	6.1 (15)	7.9 (19)	7.4 (22)	8.7 (25)	10.7 (27)	17.8 (28)
Stampede	6.3 (16)	7.7 (18)	8.6 (29)	8.7 (27)	8.4 (22)	13.2 (24)
Eclipse	7.9 (22)	8.1 (20)	7.9 (25)	8.4 (24)	10.3 (26)	11.6 (23)
Orion	7.2 (20)	8.1 (22)	8.1 (27)	8.7 (26)	9.4 (25)	14.1 (25)
Cornell 605	...	...	3.4 (02)	3.9 (02)	3.7 (02)	3.9 (02)
CNFC 9500	...	...	6.1 (16)	6.6 (15)	5.3 (09)	5.9 (09)
Majestoso	...	...	6.4 (18)	7.2 (16)	7.4 (19)	8.3 (18)
CNFC 10720	...	...	7.6 (23)	7.9 (19)	6.4 (16)	8.0 (16)
Lariat	...	...	7.4 (21)	8.0 (20)	7.6 (20)	8.9 (20)
Madrepérola	...	...	7.9 (26)	8.1 (23)	7.1 (17)	8.1 (17)
NE1-07-2	...	...	8.3 (28)	9.0 (29)	13.4 (29)	16.3 (27)
LSD (0.05)	2.92	3.45	3.34	3.31	5.15	9.79

^a For reaction scores, 1 = no infection and 9 = invasion of the third internode was higher than 2.5 cm, leading to plant death.

^b Genotypes are listed in order of sum of rankings, which are shown in parentheses after means of reaction score and lesion length. Beryl and Orion are international susceptible controls. Majestoso, Madrepérola, CNFC 9500, and CNFC 10720 are Brazilian genotypes. LSD = least significant difference.

infected tissue, 4 = 30 to 40% diseased plants or 10 to 20% infected tissues, 5 = 40 to 50% diseased plants or 20 to 30% infected tissue, 6 = 50 to 60% diseased plants or 30 to 40% infected tissues, 7 = 60 to 70% diseased plants or 40 to 50% infected tissue, 8 = 70 to 80% diseased plants or 50 to 60% infected tissues, and 9 = 80 to 100% diseased plants or 60 to 100% infected tissues (9). Severity of anthracnose, angular leaf spot, rust, and Fusarium wilt (*Fusarium oxysporum* f. sp. *phaseoli* J. B. Kendr. & W. C. Snyder) was evaluated at the R7 (pod-formation) or R8 (pod-filling) growth stage, using a scale of infection adapted from Van Schoonhoven and Pastor-Corrales (30), where 1 = no visible symptoms, 3 = light, 5 = moderate, 7 = severe, and 9 = very severe. For general consideration and simplification, genotypes with 1.0 to 3.0 scores were considered resistant, 3.1 to 6.0 intermediate, and 6.1 to 9.0 susceptible. When the disease was present in more than one experiment, we considered the highest scale to classify the genotype as resistant, intermediate, or susceptible. Yield was estimated at 13% seed moisture (dry weight basis) harvested from an area of 2 m².

Reaction of some genotypes to *C. lindemuthianum* races. A preliminary experiment in the greenhouse was conducted with lines A 195, Cornell 605, G122, and Beryl to evaluate their reaction to the *C. lindemuthianum* races 65, 73, and 89. These races are among the most frequent in Brazil (16). Races of this pathogen were obtained from the breeding program of common bean at the Federal University of Viçosa. Brazilian 'Rudá' bean (carioca class), susceptible to these races, was used as a control. At 7 DAI, the plants were scored as resistant (scale values 1 to 3) or susceptible (scale values 4 to 9) (15). A completely random design with eight replicates was used. Each plant was one replicate.

Statistical analyses. Data from the straw tests and field experiments were analyzed individually by analysis of variance (ANOVA). A combined analysis of the straw tests was not performed because the number of genotypes tested in each experiment was different. Bartlett's test for homogeneity of variances enabled combined analyses of variance across field experiments II and III, which were under

moderate WM pressure. Field experiment I was not included in the combined analyses because it was under very low WM pressure; moreover, it was the only experiment under Fusarium wilt pressure. Treatment means were separated using Fisher's protected least significant difference (LSD) at $P < 0.05$. In the straw tests, genotypes were ranked according to their means of WM reaction and lesion length; in the combined analyses of field experiments II and III, they were ranked according to their mean WM intensity score and yield. Pearson's correlations were performed to determine the relationship between (i) yield and WM intensity score, (ii) yield and other diseases, and (iii) WM intensity score in field experiments II and III and WM reaction score in the straw tests at either 7 or 14 DAI. ANOVA and LSD test were carried out using the R program.

Results

The straw test. Lines differed significantly ($P < 0.001$) for WM reaction scores and lesion lengths, with A 195, 11A-39, Cornell 603, G122, and Cornell 605 exhibiting the greatest partial resistance and NE2-06-08, Beryl, NE1-06-12, Stampede, Eclipse, Orion, and NE1-07-2 the most susceptible (Table 1). Among the Brazilian genotypes, CNFC 9500 exhibited the lowest mean of reaction scores and lesion lengths.

Field experiments. Although WM intensity was very low in experiment I, genotypes varied from susceptible to resistant to Fusarium wilt (Table 2). Brazilian Majestoso and Madrepérola as well as the international lines WM31, G122, and Tapia were resistant to this disease. Brazilian cultivars were among the genotypes with the highest yield in experiment I. The international lines A 195, P07863, and Cornell 605, all with intermediate resistance to Fusarium wilt, were also among the genotypes with the highest yield. Seven international lines were susceptible to Fusarium wilt and yielded poorly in experiment I.

Genotypes varied from susceptible to resistant to anthracnose and angular leaf spot (Table 2). The Brazilian genotypes and lines A 195, Cornell 605, WM31, G122, 29C-6, and Tapia were resistant to

Table 2. Reaction of common bean genotypes to Fusarium wilt (FuW), anthracnose (ANT), angular leaf spot (ALS), and white mold (WM) and mean yield in three field experiments

Genotype	FuW ^{a,b}	Yield (kg ha ⁻¹) ^b	ANT ^{a,c}	ALS ^{a,c}	WM ^{d,e}	Yield (kg ha ⁻¹) ^e
Majestoso	R	3,734	R	I	6.08 (23)	2,957 (04)
A 195	I	3,326	R	R	2.58 (04)	3,038 (03)
P07863	I	3,178	I	I	3.92 (10)	2,866 (05)
Madrepérola	R	2,939	R	I	5.83 (22)	2,704 (06)
Cornell 605	I	2,934	R	I	2.33 (02)	2,675 (07)
CNFC 10720	I	2,764	R	I	4.33 (14)	3,583 (01)
WM31	R	2,196	R	I	4.00 (11)	1,560 (16)
CNFC 9500	I	2,032	R	R	4.25 (13)	3,309 (02)
37-2	I	1,930	I	I	3.75 (09)	2,409 (09)
Stampede	I	1,777	I	I	4.25 (12)	1,361 (19)
G122	R	1,701	R	R	1.60 (01)	1,840 (12)
Lariat	I	1,639	I	I	4.50 (15)	2,157 (10)
NE2-07-10	I	1,609	I	I	2.67 (05)	1,645 (14)
Ex Rico 23	I	1,554	I	I	3.50 (08)	2,142 (11)
29C-6	I	1,426	R	I	5.33 (20)	1,637 (15)
B07104	S	1,425	I	S	5.17 (19)	2,623 (08)
38-4	S	1,047	I	I	3.00 (06)	1,537 (17)
NE1-07-2	S	881	I	I	4.50 (16)	1,064 (21)
Tapia	R	710	R	I	5.67 (21)	1,681 (13)
Avalanche	S	425	I	I	4.83 (18)	1,486 (18)
Orion	S	310	S	I	4.50 (17)	1,041 (22)
Eclipse	S	307	S	R	3.00 (07)	1,837 (13)
11A-39	S	178	S	I	2.42 (03)	1,104 (20)
LSD (0.05) ^f	-	1,538	-	-	3.02	1,239

^a R = resistant (values from 1.0 to 3.0), I = intermediate (3.1 to 6.0), and S = susceptible (6.1 to 9.0).

^b Experiment I (Coimbra, state of Minas Gerais, Brazil).

^c Considering the higher scores achieved in the three field experiments.

^d Intensity: 1 = no diseased plants to 9 = 80 to 100% diseased plants or 60 to 100% infected tissues. Rankings are shown in parentheses.

^e Combined analysis from experiments II and III (Oratórios and Viçosa, state of Minas Gerais, Brazil). Rankings are shown in parentheses.

^f Least significant difference.

anthracnose. Orion, Eclipse, and 11A-39 were susceptible to anthracnose in the three experiments. Orion and 11A-39 were also among the lowest-yielding lines in the combined analysis of experiments II and III. B07104 was the only line susceptible to angular leaf spot, whereas A 195, CNFC 9500, G122, and Eclipse were resistant. Rust only occurred in experiment III (data not shown); line 11A-39 was susceptible, and the Brazilian genotypes and lines A 195 and G122 were resistant. Cornell 605 had intermediate resistance to rust.

A 195, Cornell 605, G122, NE2-07-10, 38-4, Eclipse, and 11A-39 were among the genotypes most resistant to WM in the field (values ≤ 3.0) (Table 2). Of these, only A 195 and Cornell 605 were among the most productive genotypes in the three experiments. The Brazilian lines CNFC 10720 and CNFC 9500 (resistant to WM in the field) had an average WM intensity score 28% lower and an average yield 22% higher than those of Brazilian Majestoso and Madrepérola (susceptible to WM in field) in the combined analysis of experiments II and III; however, the differences between their means were not significant.

Using the combined means of experiments II and III, yield was not significantly correlated with WM intensity score ($r = 0.12$, $P = 0.60$) or with angular leaf spot score ($r = -0.25$, $P = 0.24$) but was significant with anthracnose score ($r = -0.69$, $P = 0.003$). In experiment I, yield correlated significantly with Fusarium wilt score ($r = -0.53$, $P = 0.008$) and anthracnose score ($r = -0.64$, $P = 0.001$). Correlations between the average WM intensity score in experiments II and III and the average WM reaction score in the straw tests at 7 DAI ($r = 0.44$, $P = 0.032$) and 14 DAI ($r = 0.51$, $P = 0.014$) were significant and moderate.

Reaction of some genotypes to *C. lindemuthianum* races. A 195, Cornell 605, and G122 showed complete resistance to *C. lindemuthianum* races 65, 73, and 89, whereas Beryl and the susceptible control Rudá were susceptible to these races in a preliminary test in greenhouse.

Discussion

Identifying and using sources of WM resistance based on the germplasm available in Brazil and abroad are crucial steps for developing a successful common bean breeding program. In two greenhouse (straw test) and three field experiments conducted in three districts of the Zona da Mata region, state of Minas Gerais, Brazil, we screened 23 international common bean lines with the objective to select genotypes with resistance to WM and other diseases associated with high yield potential. We found that Cornell 605, A 195, and G122 had the highest levels of WM resistance associated with field resistance or intermediate resistance to anthracnose, angular leaf spot, rust, and Fusarium wilt. In addition, our preliminary results indicate that these three lines are resistant to *C. lindemuthianum* races 65, 73, and 89, which are among the most common races in Brazil (16). In the field, G122 exhibited higher levels of Fusarium wilt resistance than Cornell 605 and A 195. These three international lines exhibited higher levels of WM resistance than the Brazilian lines, which are reported to be resistant to WM under field conditions (32). However, G122 yielded 47% less than the Brazilian lines under WM pressure, whereas yields of Cornell 605 and A 195 did not differ significantly from those of the Brazilian lines, regardless of the WM pressure (Table 2).

Common bean germplasm may respond differently to genetically distinct *S. sclerotiorum* isolates. Thus, screening germplasm against a broad spectrum of isolates from the target production region increases the chances of developing resistant cultivars (19). In the present study, we used only one isolate to test the physiological resistance to WM in common bean lines. Thus, in further studies, the lines that attract attention in this study should be tested with representative *S. sclerotiorum* isolates from Brazil. In addition, further field experiments involving these lines will allow better understanding of biotic and abiotic factors affecting their performance in Brazil.

A 195, Cornell 605, and G122 are of Andean origin, with determinate bush upright growth habit type I. In general, Andean genotypes possess comparatively higher levels of physiological resistance to WM than Mesoamerican genotypes (19). In addition, type I cultivars

generally have higher WM resistance in the field (avoidance mechanism) than genotypes with plant characteristics similar to those of the Brazilian Madrepérola and Majestoso bean. These cultivars have prostrate indeterminate growth habit (type III), which restricts sunlight penetration and air circulation in the plant canopy, favoring WM development. Type I plants also minimize contact between plants within and between rows, and between leaves or pods and residues remaining on the soil surface (31), and generate fewer senescing blossoms (11) than plants of genotypes with indeterminate growth habit. However, not all type I genotypes avoid WM equally and some are highly susceptible (19). One disadvantage of Andean bean genotypes is their inherently lower yield potential than Mesoamerican common bean genotypes (11). In this study, however, Cornell 605 and A 195 had yield potential similar to that of the Brazilian cultivars (types III) and lines (types II) even when WM pressure was low (Table 2).

A 195 is a common bean breeding line of large opaque beige seed developed by Singh et al. (22) in Colombia. This line is derived from the single-cross between Red Kloud and ICA 10009 followed by a combination of pedigree and bulk breeding methods without screening for WM response during the breeding process. Our results in Brazil confirm the partial resistance of A 195 to WM reported for the United States (4,22,26,29,33) and Spain (14,17). We also found that A 195 has high-yielding potential in part because it exhibits intermediate resistance to Fusarium wilt and resistance to rust, angular leaf spot, and anthracnose. The resistance of this line to angular leaf spot, a serious disease in Brazil, is confirmed by Viteri and Singh (33). A 195 also possesses the *I* gene for resistance to all strains of *Bean common mosaic virus* (BCMV) and moderate level of resistance to heat and drought stresses (22). In the United States, recurrent and gamete selection methods were effective for improving WM resistance in common bean using A 195 as a donor parent (27,28). Because the genetic control of WM resistance in this line is monogenic dominant in the field and recessive in the greenhouse (4), the introgression of WM resistance genes from A 195 using backcross breeding methods or molecular marker-assisted selection would also be good alternatives for breeding programs.

Cornell 605 is a light red kidney common bean. This line was developed through greenhouse selection and was evaluated for WM resistance in multistate greenhouse and field comparisons. Details of the breeding process can be found in Griffiths (5). In the present study, Cornell 605 exhibited high levels of WM and anthracnose resistance and high yield potential. This line also exhibited intermediate resistance to angular leaf spot, rust, and Fusarium wilt. Cornell 603 (dark red kidney) also showed high levels of physiological resistance to WM isolate Ss-2. Nonetheless, Cornell 603 exhibited low local adaptation because, during the seed multiplication in the greenhouse, it produced 83% fewer seed than did Cornell 605.

For successful common bean cultivar development, high levels of partial resistance to WM must be combined with high seed yield and broad adaptation to production environments (19). In this study, besides their partial resistance to WM, A 195 and Cornell 605 exhibited high-yielding potential and good levels of resistance to common diseases in Brazil. These characteristics make these lines good candidates for use by breeders to improve Brazilian lines of common bean.

G122 belongs to the cranberry common bean class. This line is a well-known source of WM resistance abroad (5,6,10,14,17,21,33). In the present study, G122 exhibited high levels of WM resistance but its yield potential was lower than that of A 195. Recently, G122 was used as the donor parent in a backcross breeding program with commercial common bean cultivars in Brazil (2). These authors obtained two progenies with high levels of physiological resistance to WM but the yield potential of these progenies was not assessed. Our results indicate that G122 may also be a useful source of resistance to Fusarium wilt, anthracnose, angular leaf spot, and rust. In addition, G122 is resistant to plant dwarfing, pod deformation, and leaf chlorosis caused by *Bean golden mosaic virus* (BGMV) (20) but it is susceptible to BCMV (33). Although BGMV can cause severe losses in Brazil, most of the recently recommended common bean cultivars

are resistant to BCMV. Thus, G122 could be a source of multiple disease resistance in common bean breeding programs and deserves further attention.

Line 11A-39 was among the genotypes most resistant to WM in the greenhouse (Table 1) and field (Table 2), confirming previous studies (8,12). Here, however, 11A-39 yielded poorly, partly due to its susceptibility to Fusarium wilt, anthracnose (Table 2), and rust. NE2-07-10 and WM31 exhibited moderate physiological resistance to WM (Table 1). NE2-07-10 showed high levels of WM resistance in the field but its yield potential was lower than that of A 195 (Table 2). WM31 exhibited Fusarium wilt and anthracnose resistance in the field but its level of WM resistance was similar to that of the Brazilian lines. In addition, WM31 yielded less than the Brazilian lines under WM pressure (Table 2). Ex Rico 23 confirms its intermediate resistance to WM (7). In the field, Ex Rico 23 exhibited intermediate resistance to Fusarium wilt, anthracnose, and angular leaf spot and yielded 53% less than A 195 without WM pressure (Table 2). Thus, these four lines seem less interesting for the common bean breeding programs in Brazil than Cornell 605 and A 195.

Lines P07863 and 37-2 were recently registered in the United States as pinto bean cultivars 'Eldorado' and 'USPT-WM-12', respectively. Eldorado may have moderate levels of physiological resistance to WM in addition to morphological avoidance mechanisms (6), and USPT-WM-12 possesses partial resistance to WM (10). In our study, however, the physiological and field resistances of these cultivars to WM were similar to those of the line CNFC 9500. This Brazilian line exhibited higher levels of resistance to anthracnose and angular leaf spot than these two international lines. Therefore, P07863 and 37-2 did not show advantages over CNFC 9500 for common bean breeding in Brazil.

Orion (11) and Beryl (5,6) are used in the United States as standard WM-susceptible controls. They also showed high susceptibility to WM in Brazil. Orion was also susceptible to anthracnose and Fusarium wilt in the field and yielded poorly in the three field experiments. Beryl was not tested in the field because insufficient seed were produced, which indicates its low adaptation to Brazilian conditions. Beryl was also susceptible to important *C. lindemuthianum* races (65, 73, and 89) in Brazil in our preliminary test. Due to the lack of a susceptible WM control for use in straw tests in Brazil, Beryl or Orion might be a good candidate for this purpose. Because these lines are susceptible to anthracnose, the use of pathogen-free seed in the straw test is needed to prevent this disease.

Using the combined means of experiments II and III, yield was not significantly correlated with WM intensity score ($r = 0.12$) but correlated significantly with anthracnose score ($r = -0.69$). These results are partly due to the high anthracnose pressure compared with the moderate WM pressure in these experiments. The use of four high-yielding Brazilian genotypes, which were classified as intermediate or susceptible to WM (Table 2), also helps to explain this lack of correlation between yield and WM intensity score. In experiment I, where WM intensity was very low, both anthracnose ($r = -0.64$) and Fusarium wilt ($r = -0.53$) were significantly correlated with yield. In this experiment, both diseases were present at high levels, and lines susceptible to them such as Orion, Eclipse, and 11A-39 yielded very poorly.

We found significant and moderate correlations ($r = 0.44$ or 0.51) between WM reaction score in the straw test and WM intensity in the field. Lower or similar levels of correlation between straw test and field evaluations in common bean have been obtained in other studies (13,23). This magnitude of correlation occurs, in part, because the straw test detects physiological resistance whereas, in the field, physiological and avoidance mechanisms act together under different WM pressure. These levels of correlation show the importance of using field experiments to fully characterize partial resistance in segregating populations (23).

In Brazil, few studies have approached the issue of using germplasm for improving resistance of common bean against WM (2,24,32). From these studies, only Vieira et al. (32) conducted experiments in a field naturally infested with sclerotia. These authors screened sources of resistance to WM using advanced common bean

lines from three Brazilian breeding programs. They found that CNFC 10720 (type II) was among the most resistant lines, which yielded much more than the type III Majestoso (2,593 versus 1,337 kg ha⁻¹). In experiment I, in which WM intensity was very low, Majestoso yielded 35% more than CNFC 10720. However, under moderate WM pressure (experiments II and III), CNFC 10720 yielded 21% more than Majestoso, thus supporting results of Vieira et al. (32). Both Brazilian genotypes have low physiological resistance (Table 1). The present study and the study of Vieira et al. (32) indicate that field screening is important for improving common bean resistance against WM.

In summary, our results suggest that the lines Cornell 605 and A 195 have high levels of WM resistance in Brazil associated with high seed yield and resistance or intermediate resistance to other common diseases in Brazil. G122 has lower yield potential than A 195. Even so, G122 deserves attention in future studies because it exhibits high levels of partial resistance to WM associated with high levels of resistance to other diseases.

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