

Department of Plant Pathology, Michigan State University, East Lansing, MI, USA

## Sources of Resistance to Anthracnose in Traditional Common Bean Cultivars from Paraná, Brazil

P. S. VIDIGAL FILHO<sup>1</sup>, M. C. GONÇALVES-VIDIGAL<sup>1</sup>, J. D. KELLY<sup>2</sup> and W. W. KIRK<sup>3</sup>

Authors' addresses: <sup>1</sup>Department of Agronomy, Maringá State University, Maringá, PR 87020-900, Brazil; <sup>2</sup>Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI 48824, USA; <sup>3</sup>Department of Plant Pathology, Michigan State University, East Lansing, MI 48824, USA (correspondence to W. W. Kirk. E-mail: kirkw@msu.edu)

Received May 3, 2006; accepted August 30, 2006

**Keywords:** *Colletotrichum lindemuthianum*, anthracnose, physiological races, pathogenicity, *Phaseolus vulgaris*, breeding

### Abstract

Pathogenicity of physiologically distinct races of *Colletotrichum lindemuthianum* originating from Andean (races 7, 19 and 55) and Mesoamerican (races 9, 31, 65, 69, 73, 81, 89, 95 and 453) locations of the new world were evaluated on 26 landrace genotypes of common bean (*Phaseolus vulgaris* L.) from Paraná State, Brazil. Races 7 (Andean), 65, 73 and 89 (Mesoamerican) were the most pathogenic, while race 31 (Mesoamerican) was the least pathogenic. Most of the landrace genotypes evaluated (88%) were resistant to race 31, except Carioca 3, Preto 1 and Preto 2. In addition, about 50% of the landrace genotypes had resistance to races 9, 19, 55 and 453; and about 30% to races 7, 65, 69, 73, 81, 89 and 95. The resistance index, which measured the pathogenicity response averaged across all the physiologically distinct Andean and Mesoamerican races of *C. lindemuthianum*, of the landrace genotypes ranged from 8% to 83%. The most resistant cultivars were Carioca Pintado 1, Carioca Pintado 2, Jalo Vermelho and Jalo de Listras Pretas. In contrast, the most susceptible cultivars were Jalo Pardo, Jalo Pintado 1 and Bolinha that showed resistance only to the least pathogenic race 31. These results indicated that many of the common bean landrace cultivars evaluated have genes that could be useful in breeding programmes to enhance resistance to Andean and Mesoamerican races of *C. lindemuthianum*.

### Introduction

Leaf and pod anthracnose (*Colletotrichum lindemuthianum* (Sacc. and Magnus) Lams.-Scrib.) of beans (*Phaseolus vulgaris*, L.) is one of the most severe and widespread diseases of common beans and occurs mainly in cool humid regions (Tu, 1992; Pastor-Corrales et al., 1995; Balardin et al., 1997; Mahuku et al., 2002; Pastor-Corrales, 2005). *C. lindemuthia-*

*num* has a broad genetic variability (Pastor-Corrales, 1991; Balardin et al., 1997; Mahuku et al., 2002), and many races of the pathogen have been characterized in different parts of the world where dry beans are grown (Yerkes and Ortiz, 1956; Menezes and Dianese, 1988; Garrido-Ramirez and Romero-Cova, 1989; Pastor-Corrales et al., 1995; Balardin et al., 1997; Mahuku et al., 2002). In studies using the binary nomenclature for *C. lindemuthianum* race characterization (Pastor-Corrales, 1991; Mahuku et al., 2002), 25 physiological races of the pathogen from several regions of Brazil were identified, of which 14 came from Paraná State and were identified as races 55, 64, 65, 81, 89, 95, 102 and 453 (Rava et al., 1994) and eight races (5, 17, 23, 31, 55, 65, 73 and 453) were identified in another collection from Rio Grande do Sul State, Brazil (Balardin, 1997). Out of 18 isolates obtained from eight traditional cropping areas in the north-west and south regions of Paraná State, nine races 7, 31, 65, 69, 73, 81, 87, 89 and 95 were identified. On average, race 89 constituted 86% of the population in these collections and was therefore predominant in the common bean growing regions of southern Brazil (Thomazella et al., 2000). Clearly, wide genetic variability exists in the populations of *C. lindemuthianum* found in Paraná State, Brazil (Thomazella et al., 2000).

The use of genetically resistant cultivars is an effective way to manage anthracnose of common bean (Muhalet et al., 1981; Kelly et al., 1994; Kelly and Vallejo, 2004). However, the wide natural variability of *C. lindemuthianum* and the potential for the appearance of new virulent races, presents a major challenge for bean breeders and plant pathologists as genetic resistance of the host may not be durable under such conditions (Mahuku et al., 2002). The production and release of cultivars from plant breeding programmes is therefore dependent on incorporating new germplasm from diverse gene

pools from which new genes can be introduced into cultivars to increase resistance (Schwartz et al., 1982; Pastor-Corrales et al., 1995; Young et al., 1998; Melotto and Kelly, 2000). The centres of origin of the cultivated bean constitute a valuable source from which these genes may be discovered (Singh et al., 1991; Geffroy et al., 1999) or from traditionally grown landrace cultivars maintained by farmers from generation to generation (Montalván and Faria, 1989). Paraná State is the main bean producing state in Brazil, and is an area where extensive genetic diversity among traditional landrace bean genotypes exists (Alberini, 2001). The objective of this study was to characterize a group of landrace bean cultivars from Paraná State for their resistance to different races of *C. lindemuthianum* present in southern Brazil.

## Materials and Methods

### Plant material

Twenty-six landrace cultivars of common bean were collected in the north, north-west and west regions of Paraná State in southern Brazil. The landrace cultivars belong to the following market class groupings: Carioca, Preto, Manteigão, Navy and Rosinha (Table 1) and additional descriptive features of the landraces can be found at <http://www.css.msu.edu/bic/PDF/Beans%20from%20Paraná%20Brazil.pdf>. Cultivars of the Carioca, Preto, Navy and Rosinha groups are small seeded types and belong to the Middle American gene pool, whereas the Manteigão (Jalo and Roxinho) group are large seeded types and belong to the Andean gene pool (Voyses et al., 1994). The anthracnose responses of these landrace cultivars to the Andean 7, 19 and 55 and Mesoamerican 9, 31, 65, 69, 73, 81, 89, 95 and 453 races of *C. lindemuthianum* were determined following the procedures of Balardin et al. (1997) and Mahuku

et al. (2002). The evaluations were conducted in laboratories and greenhouses at the Applied Agricultural Research Nucleus (Nupagri), Maringa State University (UEM), Brazil, and at the Departments of Plant Pathology and Crop and Soil Sciences at Michigan State University (MSU), USA, in the period between July 2002 and April 2003. Inoculum of the races of *C. lindemuthianum* 7, 31, 69, 73, 81, 89 and 95 was obtained from the pathogen collection at Nupagri, while inoculum of the races 9, 19, 55 and 453 was obtained from the collection at the Department of Crop and Soil Sciences (Kelly, MSU).

### Preparation of inoculum

Pods (120) were harvested from greenhouse-grown kidney beans (cv. Montcalm) 50 days after planting. Prior to inoculation, the pods were washed in distilled H<sub>2</sub>O, then surface sterilized by soaking in a 2% sodium hypochlorite (Clorox 5.25%) solution for 4 h. Pods were rinsed with distilled H<sub>2</sub>O, then dried in a controlled environment with continuous air flow at 15°C in dry air (30% relative humidity) for 4 h prior to inoculation. The sterilized bean pods were partially immersed to a depth of 0.5 cm in agar medium in Magenta boxes (agar depth 4 cm) and covered prior to inoculation.

Axenic cultures of *C. lindemuthianum* maintained on PDA (races 7, 9, 19, 31, 55, 69, 73, 81, 89, 95 and 453) were grown in the dark for 12 days at 18°C. Plugs (4 mm diameter) were excised and placed onto the sterilized bean pods partially immersed in agar medium. The inoculated pods were incubated for 12 days at 18°C until mycelium was visible and sporulation confirmed by microscopy. The pods were removed from the agar beds and the mycelia and spores were scraped from the surfaces of the pods with a sterile plastic rod into a bath of sterile distilled H<sub>2</sub>O. The mycelial/sporangial suspension was stirred with a magnetic stirrer for 1 h. The suspension was strained through four layers of cheesecloth, and the sporangial concentration was adjusted to about  $1.2 \times 10^6$  spores/ml with a haemocytometer.

The isolates used in this study represent 12 physiological races characterized previously by Balardin et al. (1997). To confirm their phenotypes, isolates were inoculated on to the same 12 international anthracnose differential bean cultivars (Pastor-Corrales, 1991) using the method of Mahuku et al. (2002). Briefly, in Brazil seeds from the 26 landrace cultivars were sown in 12 seedling plastic trays containing a mixture (3:1) of soil and organic matter sterilized with methyl bromide, and in the US seeds were planted into 12 seedling plastic trays containing Bacto planting mix (Michigan Peat Co., Houston, TX). Seedlings at both locations were grown under natural light in greenhouses supplemented by 400-W high-pressure sodium lamps giving a total light intensity of  $115 \mu\text{mol}/\text{m}^2/\text{s}$  for 7–10 days (16-h day length at 25°C) until they reached the first trifoliate leaf stage.

Table 1  
Pathogenicity index and geographical origin of Andean and Mesoamerican races of *Colletotrichum lindemuthianum*

Race	Origin	Pathogenicity index (%)
7	Andean	85
19	Andean	38
55	Andean	35
9	Mesoamerican	46
31	Mesoamerican	12
65	Mesoamerican	73
69	Mesoamerican	69
73	Mesoamerican	85
81	Mesoamerican	65
89	Mesoamerican	85
95	Mesoamerican	69
453	Mesoamerican	35

Andean was defined as originating from the centres of origin of the cultivated bean and Mesoamerican as 'middle America' as regions to where bean production has migrated. Pathogenicity index previously developed by Balardin et al. (1997) for each *C. lindemuthianum* race was computed by dividing the number of landrace genotypes of bean with a susceptible reaction by 26 (the total number of landrace genotypes of bean in this study).

### Preparation and evaluation of germplasm

The test germplasm was obtained from seed collections of landrace cultivars of *Phaseolus vulgaris* L. maintained at Maringa State University. Seedlings of the landraces and control cultivars, e.g. Navy UEM, were pregerminated by placing beans between water-soaked absorbent paper towels for 48 h. Germinated beans of individual cultivars were planted into flats as described above at Maringa State University (June 2002) and Michigan State University locations. Repetition of the experiment was carried out at Michigan State University (April 2003). Identical methodology was used for both experiments except for the makes and capacities of the controlled environment chambers.

Twelve seedlings of each cultivar were spray inoculated with 2 ml of the spore suspension of each race of *C. lindemuthianum* (Table 1), using a De Vilbiss number 15 atomizer powered by an electric compressor. The plants were treated as replicates for the experiments. After inoculation, plants were maintained at >95% relative humidity for 2 days at 21–23°C and 16-h day length (light intensity of 300  $\mu\text{mol}/\text{m}^2/\text{s}$  at 1 m height) in a reach-in controlled environment chamber (Michigan State University; M Series; Environmental Growth Chambers, Chagrin Falls, OH, USA). Plants were removed from the growth chamber and transferred to the greenhouse (16-h day length at 25°C) until evaluation.

### Evaluation and data analysis

After 10 days (15 days after inoculation), the disease reaction of each seedling was rated using a subjective evaluation. Plants with no visible disease symptoms or with only a few, very small lesions mostly on primary leaf veins covering up to 1% of the total leaf/stem area were recorded as resistant (R), whereas plants with numerous small or enlarged lesions, or with sunken cankers on both the lower sides of leaves and the seedling stem (greater than 1% total leaf/stem area), were recorded as susceptible (S). The response was considered susceptible if greater than three seedlings were evaluated as S, as described above. In the event of borderline reactions the experiments were repeated; however, in both replications of the experiment the anthracnose reactions were not ambiguous and all seedlings responded as either R or S.

A pathogenicity index (PI), previously developed by Balardin et al. (1997) for each *C. lindemuthianum* race was computed by dividing the number of bean landrace genotypes with a susceptible reaction by 26 (the total number of landrace genotypes of bean in this study). A resistance index (RI), was computed by dividing the number of landrace genotypes that exhibited a resistant reaction by 12, the total number of races of *C. lindemuthianum* used for inoculation in this study (Balardin et al., 1997).

### Comparison of anthracnose response to differential cultivars

Andean cultivars with characterized alleles at the *Co-1* locus conditioning resistance to specific races of

*C. lindemuthianum* were used to determine if the resistance pattern in two Andean landraces Jalo Vermelho and Jalo de Listras Pretas was similar in spectrum to the race differential cultivars, Michigan Dark Red Kidney (MDRK) (*Co-1*), Kaboon (*Co-1*<sup>2</sup>), Perry Marrow (*Co-1*<sup>3</sup>) and Widusa (*Co-1*<sup>5</sup>).

## Results

### Pathogenicity of different physiological races

The PI of the *C. lindemuthianum* races utilized in this study ranged from 12% to 85% (Table 1). Races 7, 65, 73 and 89 were the most pathogenic, while race 31 was the least pathogenic (Table 1). Of the Andean races, 7, 19 and 55 were the most pathogenic, with PI values of 100%, 100% and 89% respectively (Table 2). The Mesoamerican bean genotypes were more resistant than the Andean bean genotypes with PI indices from 6% to 76%. Physiological race 7 had a greater PI (76%) than races 19 and 55 (PI = 6%; Table 2). The PI of the Mesoamerican races ranged from 0 (race 31) to 89 (race 69) on the Andean bean landrace genotypes, whereas the PI of the same races ranged from

Table 2  
Reaction of Andean and Mesoamerican landrace genotypes of *Phaseolus vulgaris* and pathogenicity index of Andean races of *Colletotrichum lindemuthianum*

	Race		
	7	19	55
Andean genotype			
Jalo Listras Pretas	S	S	S
Jalo de Listras Vermelhas	S	S	S
Jalo Pardo	S	S	S
Jalo Pintado 1	S	S	S
Jalo Pintado 2	S	S	S
Jalo Vermelho	S	S	R
Jalo Mulato	S	S	S
Bolinha	S	S	S
Roxinho	S	S	S
Pathogenicity index (%)	100	100	89
Mesoamerican genotype			
Carioca 1	S	R	R
Carioca 2	S	R	R
Carioca 3	S	R	R
Carioca 4	S	R	R
Carioca 5	S	R	R
Carioca 6	R	R	R
Carioca Claro	S	R	R
Carioca Pintado 1	R	R	R
Carioca Pintado 2	R	R	R
Carioca Pitoko	S	R	R
Iapar 31	S	R	R
Preto 1	S	R	R
Preto 2	S	R	R
Preto 3	S	R	R
Preto 4	R	R	R
Rosinha	S	R	S
Navy-UEM	S	S	R
Pathogenicity index (%)	76	6	6

Pathogenicity index for Andean genotypes: number of Andean bean genotypes with susceptible reaction/9 (total number of Andean genotypes); mean of 12 reps (plants), two tests. Pathogenicity index for Mesoamerican genotypes: number of Mesoamerican bean genotypes with susceptible reaction/17 (total number of Mesoamerican genotypes); mean of 12 reps (plants), two tests.

Table 3  
Reaction of Andean and Mesoamerican landrace genotypes of *Phaseolus vulgaris* and pathogenicity index of Mesoamerican races of *Colletotrichum lindemuthianum*

	Race									
	9	31	65	69	73	81	89	95	453	
Andean genotype										
Jalo de Listras Pretas	R	R	R	R	R	R	R	R	R	S
Jalo de Listras Vermelhas	R	R	R	S	S	R	S	S	S	R
Jalo Pardo	S	R	S	S	S	S	S	S	S	S
Jalo Pintado 1	S	R	S	S	S	S	S	S	S	S
Jalo Pintado 2	R	R	R	S	R	S	S	R	R	R
Jalo Vermelho	R	R	R	S	S	R	R	R	R	R
Jalo Mulato	R	R	R	S	S	S	S	R	R	R
Bolinha	S	R	S	S	S	S	S	S	S	S
Roxinho	R	R	R	S	R	S	S	R	R	R
Pathogenicity index (%)	33	0	33	89	67	67	78	44	46	
Mesoamerican genotype										
Carioca 1	S	R	S	R	S	S	S	S	R	R
Carioca 2	S	R	S	R	S	S	S	S	R	R
Carioca 3	S	S	S	R	S	S	S	S	R	R
Carioca 4	R	R	S	R	S	S	S	S	R	R
Carioca 5	R	R	S	S	S	R	S	S	S	S
Carioca 6	S	R	S	R	S	R	S	S	R	R
Carioca Claro	R	R	S	S	S	R	S	S	R	R
Carioca Pintado 1	R	R	S	S	S	R	R	R	R	R
Carioca Pintado 2	R	R	R	S	R	R	S	R	R	R
Carioca Pitoko	S	R	S	R	S	S	S	S	R	R
Iapar 31	R	R	S	S	S	S	R	R	R	R
Preto 1	S	S	S	S	S	S	S	S	S	S
Preto 2	R	S	S	S	S	S	S	S	S	S
Preto 3	S	R	S	S	S	R	S	S	S	S
Preto 4	S	R	S	S	S	S	S	S	R	R
Rosinha	R	R	S	R	S	S	S	S	R	R
Navy-UEM	S	R	S	S	S	S	S	S	S	S
Pathogenicity index (%)	53	18	94	59	94	65	88	82	29	

Pathogenicity index for Andean genotypes: number of Andean bean genotypes with susceptible reaction/9 (total number of Andean genotypes); mean of 12 reps (plants), two tests. Pathogenicity index for Mesoamerican genotypes: number of Mesoamerican bean genotypes with susceptible reaction/17 (total number of Mesoamerican genotypes); mean of 12 reps (plants), two tests.

18 (race 31) to 94 (race 65) on the Mesoamerican bean landrace genotypes (Table 3).

#### Germplasm

Jalo de Listras Pretas was susceptible to *C. lindemuthianum* Andean races 7, 19, 55 and Mesoamerican race 453; while Jalo Vermelho was susceptible to Andean races 7, 19, 69 and Mesoamerican race 73, but resistant to Andean race 55 (Tables 2 and 3). Jalo Pardo, Jalo Pintado 1 and Bolinha were resistant only to Mesoamerican race 31 (Tables 2 and 3). Other detailed interactions of the responses of the Andean and Mesoamerican landrace bean genotypes to inoculation with Andean and Mesoamerican races are shown in Tables 2 and 3.

The RI of the nine Andean bean genotypes ranged from 8% to 67%, where the lower numbers indicate the least resistance. The RI of the 17 Mesoamerican bean genotypes ranged from 17% to 83% (Table 4). The most resistant Andean genotypes were Jalo de Listras Pretas, Jalo Vermelho, Jalo Pintado 2 and Roxinho, while the more susceptible genotypes were Jalo Pardo, Jalo Pintado 1 and Bolinha (Table 4).

Table 4  
Origin and resistance index of 26 landrace bean genotypes to Andean and Mesoamerican races of *Colletotrichum lindemuthianum*

Genotype	Origin	Resistance index
Jalo de Listras Pretas	Andean	67
Jalo de Listras Vermelhas	Andean	42
Jalo Pardo	Andean	8
Jalo Pintado 1	Andean	8
Jalo Pintado 2	Andean	50
Jalo Vermelho	Andean	67
Jalo Mulato	Andean	42
Bolinha	Andean	8
Roxinho	Andean	50
Carioca 1	Mesoamerican	42
Carioca 2	Mesoamerican	42
Carioca 3	Mesoamerican	33
Carioca 4	Mesoamerican	50
Carioca 5	Mesoamerican	42
Carioca 6	Mesoamerican	58
Carioca Claro	Mesoamerican	50
Carioca Pintado 1	Mesoamerican	75
Carioca Pintado 2	Mesoamerican	83
Carioca Pitoko	Mesoamerican	42
Iapar 31	Mesoamerican	58
Preto 1	Mesoamerican	17
Preto 2	Mesoamerican	25
Preto 3	Mesoamerican	33
Preto 4	Mesoamerican	42
Rosinha	Mesoamerican	42
Navy-UEM	Mesoamerican	17

Additional descriptive details on genotypes can be found at <http://www.css.ms.u.edu/bic/PDF/Beans%20from%20Paraná%20Brazil.pdf> (Verified 9/06). Resistance index (Balardin et al., 1997) was computed by dividing the number of landrace genotypes of bean that exhibited a susceptible reaction to inoculation by 12, the total number of races of *C. lindemuthianum* used for inoculation in this study.

#### Discussion

The PI of races 19 and 55 was greatest when inoculated on Andean genotypes, but when inoculated on Mesoamerican genotypes the indices were lower. Similar results were obtained by other researchers when inoculating *C. lindemuthianum* races 19 and 55 in Andean and Mesoamerican genotypes (Balardin et al., 1997). The reduced pathogenicity of previously determined Andean races of *C. lindemuthianum* when inoculated in Mesoamerican genotypes suggests a selection of factors of pathogenicity congruent with genetic diversity in *P. vulgaris* (Balardin et al., 1997; Balardin and Kelly, 1998).

Mesoamerican races 9, 31 and 453 had a PI that ranged from 0% to 53% in Andean and Mesoamerican bean genotypes. Race 9 was more pathogenic on Mesoamerican bean genotypes, and Mesoamerican race 453 was more pathogenic to the Andean bean genotypes. Mesoamerican races 65 and 95 had the greatest PI on Mesoamerican bean genotypes (94% and 82%), respectively, while races 69, 73, 81 and 89 were pathogenic on both Andean and Mesoamerican genotypes of beans. These results are in agreement with a recent study that indicated that races 65, 69, 73, 81 and 89 occur at a high frequency in Paraná State (Thomazella et al., 2000).

There are a limited number of Andean genes for anthracnose resistance in common bean (Van

Schoonhoven and Pastor-Corrales, 1987; Kelly and Vallejo, 2004). Recently Jalo EEP558 was shown to be susceptible to race 7 and resistant to race 73, and had the same resistance spectrum as MDRK which possesses the *Co-1* allele (Kelly and Vallejo, 2004). The comparison of resistance of Jalo Vermelho to races 31, 55 and 95 and Jalo de Listras Pretas to races 31 and 95 and those of the differential cultivars MDRK (*Co-1*), Kaboon (*Co-1<sup>2</sup>*), Perry Marrow (*Co-1<sup>3</sup>*) and Widusa (*Co-1<sup>5</sup>*) suggests that Jalo Vermelho and Jalo de Listras Pretas have a different allele at the *Co-1* locus or possess another gene that confers resistance to Andean and Mesoamerican races tested in this study (Table 5).

Mesoamerican bean genotypes with the most resistance were Carioca Pintado 1, Carioca Pintado 2, Carioca 6 and Iapar 31 (resistance indices of 67, 83, 58 and 58 respectively). Carioca Pintado 2 was susceptible only to race 69 and 89, while Carioca Pintado 1 was susceptible to races 65, 69 and 73. Iapar 31 was susceptible to races 7, 65, 69, 73 and 81. This cultivar was bred from crosses between BAC4/RAI 46//BAC2/Iguaçu/3/BAT 93/BAC4 by Paraná Agricultural Research Institute in 1990 and has been cultivated since 1990 in Paraná and São Paulo (Moda-Cirino et al., 2000). In addition to other genes for resistance to anthracnose, Iapar 31 may carry the *Co-9* gene from the cultivar BAT 93. Iapar 31 was susceptible to races 7, 65, 73 and 81 which was consistent with recent evaluations (Thomazella et al., 2000; Antunes et al., 2003).

The results show that both Andean and Mesoamerican bean genotypes evaluated in this study are genetically highly variable in response to different races of *C. lindemuthianum*. Some of this genetic material would be valuable in future bean breeding programmes as new sources of resistance to anthracnose. A clear understanding of the nature and inheritance of these resistance sources will be critical to facilitate the

transfer of resistance to different commercial bean seed types grown in Brazil.

#### Acknowledgements

P. S. Vidigal-Filho and M.C. Gonçalves-Vidigal were supported by a fellowship from CAPES/MEC-Brazil. J. Kelly and W. Kirk were supported by the Michigan Agricultural Experiment Station, USA.

#### References

- Alberini JL. Alternativas de mercado. In: Alberini JL (ed.), *Reunião Sul-Brasileira de bean*, Anais, Brazil, Londrina, 2001, pp. 79–89.
- Antunes IF, Santin RCM, Mastrantonio JJS, Chollet CB, Lopes RAM, Campos AD, Silva HT. (2003) New sources of resistance, race identification and virulence and resistance index in anthracnose research. *Annu Rep Bean Improv Coop* **46**:181–182.
- Balardin RS. (1997) Identificação de raças fisiológicas de *Colletotrichum lindemuthianum* no Rio Grande do Sul, Brazil. *Fitopatol Bras* **22**:50–53.
- Balardin RS, Kelly JD. (1998) Interaction between *Colletotrichum lindemuthianum* races and gene pool diversity in *Phaseolus vulgaris*. *J Am Soc Hortic Sci* **123**:1038–1047.
- Balardin RS, Jarosz AM, Kelly JD. (1997) Virulence and molecular diversity in *Colletotrichum lindemuthianum* from South, Central and North America. *Phytopathology* **87**:1184–1191.
- Garrido-Ramirez ER, Romero-Cova S. (1989) Identification de razas fisiológicas de *Colletotrichum lindemuthianum* en Mexico y búsqueda de resistencia genética a este hongo. *Agrociencia* **77**:139–156.
- Geffroy V, Sicard D, Oliveira JCF, Seignac M, Cohen S, Gepts P, Neema C, Langin T, Dron M. (1999) Identification of an ancestral resistance gene cluster involved in the coevolution process between *Phaseolus vulgaris* and its fungal pathogen *Colletotrichum lindemuthianum*. *Mol Plant Microbe Interact* **12**:774–784.
- Kelly JD, Vallejo VA. (2004) A comprehensive review of the major genes conditioning resistance to anthracnose in common bean. *HortScience* **39**:1196–1207.
- Kelly JD, Afanador L, Cameron LS. (1994) New races of *Colletotrichum lindemuthianum* in Michigan and implications in dry bean resistance breeding. *Plant Dis* **78**:892–894.
- Mahuku GS, Jara CE, Cajiao C, Beebe SE. (2002) Sources of resistance to *Colletotrichum lindemuthianum* in the secondary gene pool of *Phaseolus vulgaris* and in crosses of primary and secondary gene pools. *Plant Dis* **86**:1383–1387.
- Melotto M, Kelly JD. (2000) An allelic series at the *Co-1* locus conditioning resistance to anthracnose in common bean of Andean origin. *Euphytica* **116**:143–149.
- Menezes JR, Dianese JC. (1988) Race characterization of Brazilian isolates of *Colletotrichum lindemuthianum* and detection of resistance to anthracnose in *Phaseolus vulgaris*. *Phytopathology* **78**:650–655.
- Moda-Cirino V, Lollato MA, Fonseca Júnior NS, Oliari L. *Cultivares, Feijão: tecnologia de produção*, Brazil, Londrina, 2000, pp. 83–100.
- Montalván R, Faria RT. Variabilidade genética e germplasm. In: Destro D, Montalván R (eds), *Melhoramento Genético de Plantas*, Brazil, Editora Universidade Estadual, Londrina, 1989.
- Muhalet CS, Adams MW, Saetler AW, Ghaderi A. (1981) Genetic system for the reaction of field beans to beta, gamma, and delta races of *Colletotrichum lindemuthianum*. *J Am Soc Hortic Sci* **106**:601–604.
- Pastor-Corrales MA. (1991) Estandartización de variedades diferenciales y designación de razas de *Colletotrichum lindemuthianum*. *Phytopathology* **81**:694 (abstract).
- Pastor-Corrales MA. Anthracnose. In: Schwartz HF, Steadman JR, Hall R, Forster RL (eds), *Compendium of Bean Diseases*, 2nd edn. St. Paul, MN, APS Press, 2005, pp. 25–27.
- Pastor-Corrales MA, Otoyá MM, Molina A, Singh SP. (1995) Resistance to *Colletotrichum lindemuthianum* isolates from Middle America and Andean South America in different common bean races. *Plant Dis* **79**:63–67.

Table 5

Disease reaction of Jalo Vermelho, Jalo de Listras Pretas and differential cultivars MDRK (*Co-1*), Perry Marrow (*Co-1<sup>3</sup>*), Kaboon (*Co-1<sup>2</sup>*) and Widusa (*Co-1<sup>5</sup>*) to 12 races of *Colletotrichum lindemuthianum*

Race	Cultivar					
	Jalo Vermelho	Jalo de Listras Pretas	MDRK	Perry Marrow	Kaboon	Widusa
7	S	S	S	S	R	R
9	R	R	R	R	R	R
19	S	S	S	R	R	S
31	R	R	S	S	R	S
55	R	S	S	S	S	S
65	R	R	R	R	R	R
69	S	R	R	S	R	R
73	S	R	R	R	R	R
81	R	R	R	R	R	S
89	R	R	R	R	R	S
95	R	R	S	S	R	S
453	R	S	R	S	R	R

S = susceptible and R = resistant response. MDRK has same resistance pattern as Jalo EEP 558.

- Rava CA, Purchio AF, Sartorato A. (1994) Caracterização de patótipos de *Colletotrichum lindemuthianum* que ocorrem in algumas regiões produtoras de feijoeiro comum. *Fitopatol Bras* **19**:167–172.
- Schwartz HF, Pastor-Corrales MA, Singh SP. (1982) New sources of resistance to anthracnose and angular spot of beans (*Phaseolus vulgaris* L.). *Euphytica* **31**:741–754.
- Singh SP, Gepts P, Debouck D. (1991) Races of common bean (*Phaseolus vulgaris*, Fabaceae). *Econ Botan* **45**:379–396.
- Thomazella C, Gonçalves-Vidigal MC, Vida JB, Vidigal Filho PS, Rimoldi F. (2000) Identification of *Colletotrichum lindemuthianum* races in *Phaseolus vulgaris* L. *Annu Rep Bean Improv Coop* **43**:82–83.
- Tu JC. *Colletotrichum lindemuthianum* on bean population dynamics of the pathogen and breeding for resistance. In: Bailey JA (eds), *Colletotrichum Biology Pathology and Control*, Wallingdorf, UK, CABI, 1992, pp. 203–204.
- Van Schoonhoven A, Pastor-Corrales MA. *Standard System for the Evaluation of Bean Germplasm*, Cali, Colombia, CIAT, 1987, pp. 56.
- Voyses O, Valencia MC, Amezquita MC. (1994) Genetic diversity among Latin American Andean and Mesoamerican common bean cultivars. *Crop Sci* **34**:1100–1110.
- Yerkes WD Jr, Ortiz MT. (1956) New races of *Colletotrichum lindemuthianum* in México. *Phytopathology* **46**:564–567.
- Young RA, Melotto M, Nodari RO, Kelly JD. (1998) Marker-assisted dissection of the oligogenic anthracnose resistance in the common bean cultivar, 'G 2333'. *Theor Appl Genet* **96**:87–94.