Tropical Plant Pathology, vol. 37(2):95-101, 2012

www.sbfito.com.br

RESEARCH ARTICLE / *ARTIGO*

Management of white mold in type III common bean with plant spacing and fungicide

Rogério Faria Vieira[1], Trazilbo J. Paula Júnior[1], José Eustáquio S. Carneiro[2], Hudson Teixeira[1] & Telma Fallieri N. Queiroz[1]

[1]Epamig, Vila Gianetti 47, 36570-000 Viçosa, MG, Brazil; [2]Departamento de Fitotecnia, Universidade Federal de Viçosa, 36570-000 Viçosa, MG, Brazil

Author for correspondence: Rogério Faria Vieira, e-mail: rfvieira@epamig.br

ABSTRACT

White mold is a yield-limiting disease during the fall-winter season in southeastern Brazil when irrigated type III common beans are generally sown 0.5 m apart with 10 to 12 plants per meter. The aim of this study was to evaluate the efficacy of combining increased row width (RW) and reduced planting density (PD), with or without fungicide, for white mold management. Treatments were arranged as a 2^3 factorial: RW (0.50 or 0.75 m), PD (6 or 12 plants per meter), and fungicide (sprayed or unsprayed). Two trials were conducted in Viçosa, State of Minas Gerais. In 2002, the average incidence of white mold was 43.2%, the severity index, 31.1%, and the yield, 2513 kg ha^{-1}. In 2003, the values of these variables were 48.0%, 22.6%, and 2159 kg ha^{-1}, respectively. Interactions involving both RW and PD were not significant for either disease intensity or yield in the combined analysis across years. Increasing RW led to reduction in white mold intensity in 2002. The lower PD reduced disease incidence in 2002 and did not affect yield in the combined analysis. In fungicide sprayed plots, wide RW decreased yield in 2002, but RW did not affect yield in 2003. In unsprayed plots, RW did not affect yield in both years. We conclude that increasing RW to 0.75 m combined with low PD is a promising strategy for white mold management when fungicide is not applied. When fungicide is applied, the current row width (0.50 m) combined with low PD maximize the yield.
Key words: *Phaseolus vulgaris*, *Sclerotinia sclerotiorum*, integrated management, plant population, Sclerotinia stem rot.

RESUMO

Manejo do mofo-branco em feijão do tipo III com espaçamento de plantas e fungicida

O mofo-branco é doença que limita a produtividade no outono-inverno no Sudeste do Brasil, quando feijoeiros irrigados do tipo III são geralmente semeados no espaçamento entre fileiras (EEF) de 0,5 m com 10 a 12 plantas por metro. O objetivo com este estudo foi avaliar a eficácia da combinação de EEF largo, densidade de plantas (DP) baixa, com ou sem fungicida, no manejo da doença. Os tratamentos foram arranjados no fatorial 2^3: EEF (0,50 ou 0,75 m), DP (6 ou 12 plantas por metro) e fungicida (com ou sem). Dois ensaios foram conduzidos, em Viçosa, MG. Em 2002, a incidência média do mofo-branco foi de 43,2%, a severidade de 31,1% e a produtividade de 2513 kg ha^{-1}. Em 2003, os valores dessas variáveis foram: 48,0%, 22,6% e 2159 kg ha^{-1}, respectivamente. As interações que envolveram EEF e DP não foram significativas em relação à intensidade da doença e à produtividade na análise combinada dos anos. EEF largo reduziu a intensidade do mofo-branco em 2002. DP baixa reduziu a incidência em 2002 e não influenciou a produtividade na análise combinada. Nas parcelas com fungicida, EEF largo diminuiu a produtividade em 2002, mas EEF não influenciou a produtividade em 2003. Nas parcelas sem fungicida, EEF não influenciou a produtividade nos dois anos. Concluímos que a combinação de EEF largo e DP baixa é uma estratégia promissora para o manejo do mofo-branco quando não se aplica fungicida. Quando se aplica fungicida, o espaçamento entre fileiras normalmente usado (0.50 m) associado a DP baixa maximiza a produtividade.
Palavras-chave: *Phaseolus vulgaris*, *Sclerotinia sclerotiorum*, manejo integrado, população de plantas.

INTRODUCTION

In the 2010/2011 season, common bean (*Phaseolus vulgaris* L.) production in the State of Minas Gerais, Brazil, was estimated at 601 900 t. Approximately 33% of this production was from irrigated areas cultivated during the fall-winter season, with an average yield estimated at 2644 kg ha^{-1} (CONAB, 2011). One of the most important diseases affecting common bean in these areas is white mold, caused by the fungus *Sclerotinia sclerotiorum* (Lib.) de Bary. The type III cultivars generally used in this production system are prone to outbreaks of white mold. The cultivars are generally sown at row spacing of 0.50 m, with 10 to 12 plants per meter (Paula Júnior et al., 2008).

The most commonly used control measure is the application of fungicides. Fluazinam is among the most effective fungicides used for white mold control in Brazil (Oliveira et al., 1999; Vieira et al., 2001; Vieira et al., 2003). However, owing either to the high cost of the fungicides or to requirements of organic agriculture, some farmers do not use them.

At least eight studies have investigated the effect of row widths, planting densities, or both for white mold management on prostrate, indeterminate type III growth habit cultivars of common bean (Tu, 1987; Park, 1993; Saindon et al., 1993; Saindon et al., 1995; Napoleão et al., 2006; Peachey et al., 2006; Paula Júnior et al., 2009; Vieira et al., 2010). Five of those studies focused on the effect of row widths (Tu, 1987; Park, 1993; Saindon et al., 1993; Napoleão et al., 2006; Peachey et al., 2006). In general, disease intensity (encompassing disease incidence and severity) tended to decrease when row width was increased (Tu, 1987; Park, 1993; Peachey et al., 2006) or it was not affected by row width, and yield tended to decrease as row width was increased (Park, 1993; Saindon et al., 1993; Napoleão et al., 2006). Planting density was studied by Saindon et al. (1995), Paula Júnior et al. (2009), and Vieira et al. (2010). Saindon et al. (1995) studied the effect of four planting densities (25, 35, 50, and 60 plants/m^2) at a constant row width of 0.23 m. However, these planting densities did not affect white mold incidence. Paula Júnior et al. (2009) verified that the reduction from 12 to 6 plants per meter decreased disease severity without affecting yield, whereas Vieira et al. (2010) showed that reduction of 15-16 plants per meter to 4-5 plants per meter reduced disease intensity and increased yield. The two latter studies were carried out in Brazil using a constant row width of 0.50 m. Results of these eight studies indicate that the use of low planting density can be more effective than wide row width for white mold management, but no study tested the effect of combining low planting density, wide row width, and fungicide treatment.

The aim of this study was to evaluate the efficacy of combined wide row width and low planting density, with or without fungicide, on white mold management for type III common bean.

MATERIALS AND METHODS

Research location and cultivar

Field experiments were conducted with the common bean cultivar 'Pérola' in 2002 and 2003 in an area located at the Universidade Federal de Viçosa (20°45'14'' S, 42°52'55'' W, elevation 648 m), Viçosa, State of Minas Gerais, Brazil. 'Pérola' is widely used in Brazil and it is susceptible to white mold. It has a prostrate, indeterminate type IIIa growth habit and belongs to the "carioca" (cream-striped) grain class. The field was naturally infested with sclerotia of *S. sclerotiorum* produced by 'Pérola' and had a 77.8% incidence of white mold in 2001 (Vieira et al., 2010). The soil at the site is classified as Alfissol, with the following characteristics at a depth of 0 to 0.20 m: 53% clay, 24% silt, 23% sand, and a pH of 5.8.

Treatments and design

The treatments were arranged as 2^3 factorial combinations of row widths of 0.50 or 0.75 m, planting densities of 6 or 12 plants per meter, and sprayed or unsprayed with fungicide for white mold management. The planting densities were obtained by seeding the rows with 50% more seeds than desired densities and subsequent thinning at the V3 growth stage (one trifoliolate leaf) to nearly uniform distances between plants. In 2002, with the desired density of 6 plants per meter, the plant population per hectare at harvest was 122 300 with the row width of 0.50 m (6.1 plants per meter) and 81 300 with the row width of 0.75 m (6.1 plants per meter). In 2003, it was 118 300 (5.9 plants per meter) and 78 300 (5.9 plants per meter), respectively. In 2002, with the desired 12 plants per meter, the final plant population per hectare was 218 300 with the row width of 0.50 m (10.9 plants per meter) and 135 600 with 0.75 m between rows (10.2 plants per meter). In 2003, it was 241 200 (12.1 plants per meter) and 155 600 (11.7 plants per meter), respectively. The fungicide fluazinam (Frowncide 500 SC) was used at 0.75 kg ha^{-1}. In both experiments, fluazinam was applied with a CO_2-pressurized backpack sprayer equipped with two hollow cone nozzles calibrated to deliver 530 L ha^{-1} aqueous solution at 207 kPa. In 2002, fluazinam was applied at both 52 (80% of plants with at least one open flower, R6 stage) and 66 days after emergence - DAE (all plants simultaneously with flowers and small pods, R7 stage). The manufacturer's instructions for white mold control on common bean are one application of fluazinam at flower onset followed by one or two applications at 7 to 10 day intervals at the rate of 0.50 to 0.75 kg ha^{-1}. The second fluazinam application was delayed beyond the tenth day because no diseased plant was observed until the fourteenth day when application was made. In 2003, fluazinam was applied at both 43 (5% of plants with at least one open flower, end of the R5 stage) and 53 DAE (all plants simultaneously with flowers and small pods, R7 stage). The latter application was made even with no symptoms of disease on plants. A randomized complete block design with six replicates was used.

Plot details and cultural practices

Seeds were sown on 14 May 2002 and 16 April 2003. Each plot was 3 m wide and consisted of four (0.75 m between rows) or six rows (0.50 m between rows) by 5 m long. The space between plots and blocks was 1 m. At planting, a commercial fertilizer (8 N: 12.2 P: 13.2 K) was applied in bands along with the seeds at 400 kg ha^{-1}. The area was irrigated with overhead impact sprinklers spaced 12 m apart and positioned 1.5 m above ground level. Irrigation was provided as needed to promote good seedling emergence and at a rate of approximately 5.0 cm of water once a week thereafter, as generally practiced in the region. Urea (100 kg ha^{-1}) was applied as a side dressing at V4 growth stage (third trifoliolate leaf). At this time, plants were also sprayed with a solution of sodium molybdate (0.08 kg ha^{-1}). The herbicide metolachlor (1.5 kg ha^{-1}) was applied 1 d after planting. In 2002, a commercial mixture of the herbicides fomesafen at 0.25 kg ha^{-1} and fluazifop-p-butyl at 0.20 kg ha^{-1} was applied at V4 stage. In 2003, manual hoe-weeding was made at V3 and V4 stages. Control of pests, especially leafhopper (*Empoasca kraemeri* Ross & Moore, 1957), was made with the insecticide metamidophos (0.4 kg ha^{-1}) at V4 and R6 stages. Besides the application of fluazinam, plants were preventively sprayed at V4 stage with the fungicide azoxystrobin at 0.08 kg ha^{-1} to control foliar fungal diseases. Plants were harvested when at least 90% of the pods had a brownish tan. The external rows and 0.5 m at both ends of the plot were discarded. For the row width of 0.5 m an additional external row was discarded. Then, two areas inside the plot were harvested separately: two (0.75 m) or three (0.50 m) rows, one area with 1 m of length and another with 3 m of length.

Data collection

Five weather variables (precipitation, maximum and minimum temperature, sunshine duration, and relative humidity) were recorded hourly during the growing season at an automatic weather station distant about 300 m from the experiments. Data were reported as monthly means (Table 1). Data were obtained for white mold incidence and severity, seed yield, and seed yield components. The dates of emergence (when rows of plants were visible), flowering (5% or 80% of plants with at least one open flower) and harvest in each year are provided in footnotes in Table 1. The plants in each plot were rated for disease severity index (DSI) and disease incidence (Kolkman & Kelly, 2002) by means of a "quarter scale" (Hall & Phillips, 1996). The plants were rated from 0 to 4, where 0 = no symptoms, 1 = 1% to 25% of the plant with symptoms, 2 = 26% to 50%, 3 = 51% to 75%, and 4 = 76% to 100% of the plant with symptoms. The DSI was calculated for each plot on a percentage basis by the following equation: DSI(%) = ∑(scores of all plants)/[4 x (total number of plants)] x 100. Four yield components were recorded: final plant population, pods per square meter, seeds per pod, and 100-seed weight. Pods per square meter, seeds per pod, and 100-seed weight were determined from the area of 1.5 m^2. The seed yield and final plant population were determined from an area of 6 m^2 (1.5 + 4.5 m^2). The seed moisture was adjusted to 12% (dry weight basis).

Analysis of the data

Data were analyzed for homogeneity of variance with Bartlett's test and for normality with Lilliefors's test. White mold incidence and DSI did not meet the homogeneity of variance and/or normality assumption. Thus, they were transformed using arcsine square root before analysis. The analysis of variance was used to determine the significance of effects of spacing factors, fungicide treatments, and their interactions. The combined analysis of variance was performed across years. Years and replications were considered random effects, whereas row width, planting density, and fungicide treatment were fixed effects. The combined analysis was made according to the method described in details by Carmer et al. (1989). Significant *F* ratio was used to determine significant differences between mean values. All analysis were performed using the SAEG software package (Ribeiro Júnior, 2001).

RESULTS

Weather, first symptoms of white mold, and growth cycle of common bean

In both years, rainfall during the reproductive stage of common bean was scarce (Table 1). The maximum temperature during the R6 stage (flowering) was higher in 2003 (27.0ºC) than in 2002 (24.9ºC), but the opposite occurred with the minimum temperature (11.2 and 12.5ºC, respectively). Days were cloudier during the reproductive stage of plants in 2002 (204 h of sunshine in July and 203 h in August) in contrast with 2003 (253 h of sunshine in June and 246 h in July). During the crop maturation period, higher relative humidity occurred in 2003 (79 %) than in 2002 (70 %) (Table 1). In 2002, the first symptoms of white mold were noticed at 66 DAE (R7 stage), when the last fungicide application was made. In 2003, the first symptoms were also observed at 66 DAE, but 13 days after the last fungicide application. In 2002, plants required 101 to 109 days to reach maturity from emergence; in 2003, 108 to 113 days.

TABLE 1 - Average monthly weather conditions during two growing seasons obtained from a station distant about 300 m from the experiments

Month	Precipitation (mm)		Temp., max. (ºC)		Temp., min. (ºC)		Sunshine duration (h)		Relative humidity (%)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Apr.[1]	-	16.6	-	28.4	-	16.6	-	195	-	80
May[1]	37.6	21.2	26.4	26.0	15.2	12.7	226	230	83	80
June[2]	2.2	0.0	26.2	27.0	12.1	11.2	224	253	81	80
July[2]	1.6	7.5	24.9	25.4	12.5	10.2	204	246	79	79
Aug.[3]	0.1	49.8[4]	27.7	24.4	13.0	12.2	203	176	70	79

[1]Emergence date: 24 May 2002 and 24 April 2003.
[2]Flowering date: 15 July 2002 (80% of plants with at least one open flower) and 6 June 2003 (5% of plants with at least one open flower).
[3]Harvest date: 3 to 11 Sep. 2002 and 10 to 15 Aug. 2003.
[4]1.2 mm of rainfall occurred before the end of common bean harvest.

White mold intensity

In 2002, the average incidence was 43.2% and the DSI, 31.1%, whereas in 2003, they were 48.0% and 22.6%, respectively. The year x row width interaction was significant for disease intensity (Table 2). Row width did not affect white mold incidence and DSI significantly in 2003 (Table 3). In 2002, however, the row width of 0.75 m reduced the incidence by 33% and DSI by 39% compared with 0.50 m. The year x planting density interaction was significant for disease incidence (Table 2). Planting densities did not affect incidence significantly in 2003, but incidence was 30% lower with 6 than with 12 plants per meter in 2002 (Table 4). The year x fungicide treatment interaction was significant for disease intensity (Table 2). Fungicide applications reduced both incidence and DSI relative to unsprayed plots, especially in 2002 (Table 5).

Seed yield and yield components

In 2002, the average seed yield was 2513 kg ha^{-1}; in 2003, 2159 kg ha^{-1}. Planting density and interactions involving this factor did not affect yield significantly in the combined analysis across years (Table 2). The year x planting density interaction was significant for pods m^{-2} and 100-seed weight (Table 2). In 2002, planting density did not affect significantly any yield component (data not shown). In 2003, greater numbers of pods m^{-2} were produced with 12 compared with 6 plants per meter (255.4 ± 52.9 vs 210.4 ± 14.5, n = 24, P = 0.0003). This greater number of pods m^{-2} produced with 12 plants per meter was totally compensated by plants in the low density that produced greater number of seeds per pod (4.62 ± 0.43 vs 4.48 ± 0.54, n = 24, P = 0.31) and heavier seeds (28.1 ± 1.6 vs 25.8 ± 2.1 g per 100 seeds, n = 24, P = 0.0001).

The year x row width x fungicide treatment interaction was significant for yield, pods m^{-2}, and seeds per pod (Table 2). In 2002, row width of 0.50 m, relative to 0.75 m, increased yield significantly in sprayed plots (Table 6). The greater number of pods m^{-2} produced by plants in the row width of 0.50 m (272 ± 27 vs 214 ± 19, n =12) was partially compensated by the greater number of seeds per pod (5.02 ± 0.31 vs 4.76 ± 0.34, n =12) and the heavier seeds (27.2 ± 1.1 vs 26.5 ± 1.2 g per 100 seeds, n = 12) produced by plants in the spacing of 0.75 m between rows. In unsprayed plots, row width did not affect yield significantly. In this case, the greater number of pods m^{-2} produced by plants in the row width of 0.50 m (223 ± 34 vs 214 ± 46, n = 12) was totally compensated by the greater number of seeds per pod (4.76 ± 0.25 vs 4.44 ± 0.36, n = 12) and the heavier seeds (25.4 ± 1.4 vs 24.5 ± 1.3 g per 100 seeds, n = 12) produced by plants in the spacing of 0.75 m. The yield differences between sprayed and unsprayed plots were higher in the row width of 0.50 m compared with 0.75 m. In 2003, there was no significant difference between the yield means (Table 6).

DISCUSSION

According to Peachey et al. (2006), widening row width may allow growers to suppress white mold in snap beans when fungicides are not applied. These authors tested four row widths (0.19, 0.38, 0.75, and 1.50 m) in a constant seeding rate of 445 000 seeds ha^{-1}, with or without the

TABLE 2 - Mean square of white mold intensity, seed yield, and seed yield components in combined ANOVA in 2002 and 2003

Source of variation	df	Incidence	DSI[1]	Yield	Pods m^{-2}	Seeds pod m^{-1}	100-seed weight
Year (Y)	1	360	408	3015532	270	0.90	25
Rep/year	10	231	240	481376	2834	0.11	2.3
Row width (RW)[2]	1	284	250	760200*	28532*	0.28	35
Planting density (PD)[2]	1	593	1070	20871	17469	0.62*	41
Fungicide treatment (FT)[2]	1	5480	5292	2988318	11506	0.25	47
Y x RW	1	1815**	1318***	1006	83	0.76**	4.7
Y x PD	1	669*	289	181353	7758**	0.00	23**
Y x FT	1	991*	467*	1984472***	754	0.90**	5.9
RW x PD[3]	1	321	229	46333	98	0.00	1.3
RW x FT[3]	1	91	47	93660	1512	0.20	0.1
PD x FT[3]	1	330	259	161527	2214	0.08	0.1
Y x RW xPD	1	72	27	62576	8	0.00	0.2
Y x RW x FT	1	32	51	435436*	4361*	0.36*	0.0
Y x PD x FT	1	15	4	27546	291	0.49	5.1
RW x PD x FT[4]	1	3	0.4	235537	455	0.06	3.4
RW x PD x FT x Y	1	3	0.0	27637	213	0.10	0.8
Error	70	151	103	85709	990	0.08	1.4

*P < 0.05, ** P < 0.01, *** P < 0.001.
[1]DSI = disease severity index.
[2]Significance tested using Y x RW, Y x PD or Y x FT as an error term.
[3]Significance tested using Y x RW x PD, Y x RW x FT or Y x PD x FT as an error term.
[4]Significance tested using RW x PD x FT x Y as an error term.

TABLE 3 - Year x row width interaction on white mold intensity variables (%) on common bean in Viçosa, State of Minas Gerais, Brazil

Row width (m)	Incidence[1]		Disease severity index[1]	
	2002	2003	2002	2003
0.50	51.9	43.6	38.5	19.7
0.75	34.6	52.4	23.5	25.5
Difference	17.3**	8.8ns	15.0**	5.8ns

**$P \leq 0.01$; ns: not significant at $P < 0.05$.
[1]Data are pooled across fungicide treatments and planting densities, and were transformed using arcsine square root before analysis; but non-transformed means are presented.

TABLE 4 - Year x plant density interaction on white mold incidence (%) on common bean in Viçosa, State of Minas Gerais, Brazil

Plant density	Incidence[1]	
	2002	2003
12	50.9	47.7
6	35.6	48.3
Difference	15.3*	0.6ns

*$P < 0.05$; ns: not significant at $P < 0.05$.
[1]Data are pooled across fungicide treatments and row widths, and were transformed using arcsine square root before analysis; but non-transformed means are presented.

TABLE 5 - Year x fungicide treatment interaction on white mold intensity variables (%) on common bean in Viçosa, State of Minas Gerais, Brazil[1]

Fungicide treatment	Incidence		Disease severity index	
	2002	2003	2002	2003
Sprayed	26.8	40.9	16.5	15.2
Unsprayed	59.7	55.1	45.7	30.0
Difference	32.9***	14.2**	29.2***	26.8**

$P < 0.01$;* $P < 0.001$.
[1]Data are pooled across plant densities and row widths, and were transformed using arcsine square root before analysis; but non-transformed means are presented.

TABLE 6 – Year x row width x fungicide treatment interaction on seed yield (kg ha^{-1}) of common bean in 2002 (outside the parentheses) and 2003 (within the parentheses), in Viçosa, State of Minas Gerais , Brazil

Row width	Fungicide treatment[1]		Difference[2]
	Sprayed	Unsprayed	
0.50 m	3018 (2247)	2180 (2255)	838***(-8 ns)
0.75 m	2650 (2135)	2206 (1998)	444**(137ns)
Difference[3]	368** (112 ns)	26ns (257 ns)	

** = $P < 0.01$; *** $P < 0.001$; ns: not significant at $P < 0.05$.
[1]Fluazinam was applied at R6 and R7 stages at 0.75 kg ha^{-1} in 530 L ha^{-1}. Data are pooled across planting densities.
[2]Comparisons of fungicide treatments within each row width.
[3]Comparisons of row widths within each fungicide treatment.

fungicide vinclozolin. In our study, the lack of interaction involving both row width and planting density indicates that the benefit of wide row width when no fungicide is applied might be associated to the benefit of low planting density (can decrease white mold incidence and did not affect yield). Thus, this plant arrangement might be an interesting option for white mold management for farmers that do not rely on fungicides for white mold control and, also, for those dedicated to organic production systems. In both cases, even a small yield reduction with the use of wide row widths and low planting density would be compensated by the lower production cost (less seeds per hectare, lower tractor fuel consumption, and lower labor costs for harvest).

When an effective fungicide was applied twice, our results suggest that no positive effect is gained on crop yield by changing the current row width of 0.5 m (Tables 6). According to Peachey et al. (2006), when efficacious fungicides are available, optimum yields are often equated with narrow between-row spacing and higher planting density. However, low planting density of type III common bean can decrease white mold incidence (Table 4) and did not affect yield, regardless of row width and fungicide application (Table 2). Thus, when fungicide is applied, plant arrangement should be 0.5 m between rows with 6 plants per meter. These results are supported by two studies with type III common bean involving planting densities in condition of white mold in Minas Gerais (Paula Júnior et al., 2009; Vieira et al., 2010).

In 2000, in the study of Vieira et al. (2010), when disease pressure was very high, rainfall intensity and frequency and relative humidity during the reproductive growth of common bean were higher, and maximum temperatures and sunshine duration were lower compared with 2002 and 2003 (Table 1). Except for cloudier days during the reproductive stages of plants in 2002, significant differences in weather conditions did not occur between 2002 and 2003. The longer period between the last fungicide application and the beginning of white mold symptoms in 2003 (13 days) relative to 2002 (the same day) might partially explain the relatively lower effect of the fungicide on disease control in 2003 (Table 5).

Fungicide was more effective than wide row width or low within-row density for white mold control (Tables 3, 4, and 5) and for optimum yield (Table 6). However, fungicide did not increase yield in 2003 (Table 6), maybe because white mold symptoms occurred 13 days after the last fungicide application and disease developed slower than in 2002. The average yield achieved with fungicide applications (2513 kg ha^{-1}) was close to the average yield obtained in irrigated areas of Minas Gerais during the fall-winter season (CONAB, 2011). Fluazinam protects flowers and necrotic tissues against *S. sclerotiorum* (Tu, 1987), exerts a direct effect on the fungus structures on the soil (Oliveira et al., 1999; Vieira et al., 2003), and provides control of foliar diseases such as anthracnose [*Colletotrichum lindemuthianum* (Sacc. & Magn.)] and angular leaf spot

[*Pseudocercospora griseola* (Sacc.) Crous & Braun] (Vieira et al., 2003; Vieira et al., 2010). In the 2002 experiment, fluazinam also decreased rust [*Uromyces appendiculatus* (Pers.) Unger var. *appendiculatus*] severity ($P < 0.001$) from low to very low (data not shown). Wide rows and less dense stand, on the other hand, promote more canopy air movement and reduce soil and plant surface moisture (Tu, 1987; Park, 1993), plant-to-plant transfer of mycelia (Chad et al., 2005), and plant mortality. In the present and previous study (Vieira et al., 2010), high plant mortality rates occurred more intensively in high rather than in low plant density. High plant density favors infection associated with necrotic tissues in contact with sclerotia on the soil surface (Tu, 1987). Most foliar diseases of common bean are also less intense in low plant populations (Schwartz, 1981; Vieira & Paula Júnior, 2006). The use of fungicide leads to increased production cost and environmental hazard problems, whereas reduced plant population allows reduced production cost without environmental disturbances. The different mechanisms by which fungicide and low plant population reduce white mold development might explain the lack of interaction involving both planting density and fungicide treatment on disease intensity and yield. These results are in accordance with a recent report by Vieira et al. (2010) who found that the effect of low plant density and fungicide is additive on white mold control. Increasing row width from 0.50 to 0.75 m reduces more strongly light interception efficiency by plant canopies than the reduction from 12 to 6 plants per meter. When fungicide was not applied, the possible reduction of white mold intensity with 0.75 m apart might have compensated the reduction of light interception by plant canopies and maintained the yield potential. In 2002, when fungicide was very effective, the disadvantage of the large row width was proportionally higher than its advantage. Thus, in this case, yield was higher with 0.50 m between rows than with 0.75 m. The year x row width x fungicide treatment interaction on yield discloses this situation.

These findings may not be applicable to determinate growth habit (type I) or indeterminate growth habit (type II) common bean cultivars, since such plants do not exhibit phenotypic plasticity as the type III plants to compensate for low plant density, wide row width, or both.

Results suggest that greater number of pods m^{-2} produced by type III plants in the current plant arrangement (0.50 m between rows and 12 plants per meter) is partially (with fungicide application) or totally (without fungicide) compensated by the plants in low stand (0.75 m between rows and 6 plants per meter) with both greater number of seed per pod and, especially, heavier seeds. However, when keeping 0.50 m between rows and reducing planting density to 6 plants per meter, the lower number of pods m^{-2} produced with this low plant population is totally compensated by the greater number of seed per pod and, especially, by the heavier seeds.

Our studies over two seasons illustrate the potential of improvement of white mold management with the use of either 0.50 m between row and low planting density (when fungicide is applied) or wide row width and low planting density (when no fungicide is applied).

ACKNOWLEDGEMENTS

Research and authors were supported by Fundação de Amparo à Pesquisa do Estado de Minas Gerais - FAPEMIG and Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq, Brazil.

REFERENCES

Carmer SG, Nyquist WE, Walker WM (1989) Least significant differences for combined analyses of experiments with two- or three- factor treatment designs. Agronomy Journal 81:665-672.

Chad DL, Renner KA, Penner D, Hammerschmidt R, Kelly JD (2005) Glyphosate-resistant soybean management system effect on Sclerotinia stem rot. Weed Technology 19:580-588.

Companhia Nacional de Abastecimento (2011) Safra 2010/2011. http://conab.gov.br/ OlalaCMS/uploads/arquivos/11_09_09_08_55_35_boletim_setembro_-_2011..pdf. Accessed 01 November 2011.

Hall R, Phillips LG (1996) Evaluation of parameters to assess resistance of white bean to white mold. Annual Report of the Bean Improvement Cooperative 39:306-307.

Kolkman JM, Kelly JD (2002) Agronomic traits affecting resistance to white mold in common bean. Crop Science 42:693-699.

Napoleão R, Café Filho AC, Lopes CA, Nasser LCB (2006) Effect of plant spacing and bean cultivar on white mold and seed sanity. Summa Phytopathologica 32:63-66.

Oliveira SHF, Kimati H, Tofoli JG (1999) Differential action of fungicides on life cycle of *Sclerotinia sclerotiorum* of bean. Summa Phytopathologica 25:256-261.

Park SI (1993) Response of bush and upright plant type selections to white mold and seed yield of common beans grown in various row widths in southern Ontario. Canadian Journal of Plant Science 73:265-272.

Paula Júnior TJ, Vieira RF, Teixeira H, Coelho RR, Carneiro JES, Andrade MJB, Rezende AM (2008) Informações técnicas para o cultivo do feijoeiro-comum na região central brasileira: 2007-2009. Viçosa, Minas Gerais, Brasil. EPAMIG.

Paula Júnior TJ, Vieira RF, Rocha PRR, Bernardes A, Costa EL, Carneiro JES, Vale FXR, Zambolim L (2009) White mold intensity on common bean in response to plant density, irrigation frequency, grass mulching, *Trichoderma* spp., and fungicide. Summa Phytophatologica 35:44-48.

Peachey E, Ludy RL, Powelson ML, McGrath DM (2006) Modification of plant arrangement suppresses white mold of snap beans. HortScience 41:1298-1302.

Ribeiro Júnior JI (2001) Análises estatísticas no SAEG. Viçosa, Minas Gerais, Brasil. Editora UFV.

Saindon G, Huang HC, Kozub GC, Mündel HH, Kemp GA

(1993) Incidence of white mold and yield of upright bean grown in different planting patterns. Journal of Phytopathology 137:118-124.

Saindon G, Huang HC, Kozub GC (1995) White-mold avoidance and agronomic attributes of upright common beans grown at multiple planting densities in narrow rows. Journal of the American Society for Horticultural Science 120:843-847.

Schwartz HF (1981) Interaction between plant density and bean disease severity in Colombia. Annual Report of the Bean Improvement Cooperative 24:62-63.

Tu JC (1987) Epidemiology of white mold (*Sclerotinia sclerotiorum*) in navy bean (*Phaseolus vulgaris*). Meddelingen Faculteir Landbouwwetenschappen Rijksuniversiteit Gent 52:787-796.

Vieira RF, Paula Júnior TJ, Peres AP, Machado JC (2001) Fungigation on white mold control of common bean and seed transmission of the pathogen. Fitopatologia Brasileira 26:770-773.

Vieira RF, Pinto CMF, Paula Júnior TJ (2003) Chemigation with benomyl and fluazinam and their fungicidal effects in soil for white mold control on common beans. Fitopatologia Brasileira 28:245-250.

Vieira RF, Paula Júnior TJ (2006) Sementes: Veículos de disseminação de patógenos. In: Vieira C, Paula Júnior TJ, Borém A (Eds.) Feijão. Viçosa, Minas Gerais, Brasil. Editora UFV. pp 437-476.

Vieira RF, Paula Júnior TJ, Teixeira H, Carneiro JES (2010) White mold management in common bean by increasing within-row distance between plants**.** Plant Disease 94:361-367.

TPP 439 - Received 9 November 2011 - Accepted 15 March 2012
Section Editor: Emerson M. Del Ponte