



Management of white mold of soybean using winter cereal straw

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ABSTRACT: *The management of white mold (*Sclerotinia sclerotiorum*(Lib.) De Bary) has been one of the main production limitations faced by soybean (*Glycine max* L.) producers. Considering the complex management of this disease and resistance structure of the pathogen, the present study was conducted in the municipalities of Guarapuava and Palmas in Paraná with the objective of managing the white mold of soybean using straws of winter cereals, such as oat, rye, and triticale. Initially, the three winter cereals were cultivated simultaneously in both the study areas. Straw production, plant height, and shoot fresh and dry weight were evaluated. Subsequently, BMX Apollo soybean was cultivated on cereal straws, and the incidence and severity of white mold were evaluated. In the in vitro experiment, 20 sclerotia covered by a layer of cereal (oat, rye, and triticale) straws were added and carpogenic germination was observed only in the control treatment after 98 days. Regardless of the study site, rye presented greater height and fresh weight than the remaining two cereals. Soybean cultivation on winter cereal straw reduced the incidence and severity of white mold. Cultivation on rye straw reduced mold incidence by 77.7% and 76.6% in Palmas and Guarapuava, respectively.*

Key words: *Sclerotinia sclerotiorum, Glycine max, straw, No-till, disease management.*

Manejo do mofo-branco na cultura da soja pelo uso de cobertura do solo com cereais de inverno

RESUMO: *O manejo do mofo branco (*Sclerotinia sclerotiorum*) tem sido um dos principais limitantes de produção enfrentados por produtores de soja. Tendo em vista a complexidade do manejo desta doença e da estrutura de resistência do patógeno, o presente trabalho foi conduzido nos municípios de Guarapuava e Palmas - Paraná visando o manejo do mofo branco na cultura da soja utilizando palhadas de cereais de inverno, aveia, centeio e triticale. Inicialmente, cultivou-se os diferentes cereais de inverno, simultaneamente, nas duas áreas de estudo (Guarapuava e Palmas - PR). Avaliou-se a produção de palhada, a altura de plantas, a massa verde e seca da parte aérea. Posteriormente, semeou-se soja 'BMX Apolo' sobre as palhadas de cereais e avaliou-se a incidência e a severidade do mofo branco. No experimento in vitro, adicionou-se 20 escleródios cobertos por uma camada de palhas (aveia, centeio e triticale) e após 98 dias, observou-se germinação carpogênica somente no tratamento testemunha. Independentemente do local de estudo, o centeio destacou-se com maiores altura e massa verde. O cultivo sobre palhada de cereais de inverno reduziu a incidência e severidade de mofo branco com destaque para a palhada de centeio, reduzindo a incidência da doença em 77,7% e 76,6%, em Palmas e Guarapuava, respectivamente.*

Palavras-chave: *Sclerotinias clerotiorum, Glycine max, palhada, plantio direto, manejo de doenças.*

INTRODUCTION

White mold, caused by the fungus *Sclerotinia sclerotiorum* (Lib.) De Bary, affects approximately 650 plant species, particularly soybean (*Glycine max* L.). In Brazil, the incidence of soybean white mold has significantly reduced crop production (TUPICHET et al., 2017).

High humidity and temperatures between 10 °C and 21 °C favor carpogenic germination, which is characterized by the emission of apothecia containing asci and ascospores that are disseminated

by the wind for 2 to 3 weeks. The management of soybean white mold generally involves an integrated program of measures including cultural practices, since chemical control alone is inefficient. The use of a physical barrier, derived from conventional crop remains, can affect the carpogenic germination of *S. sclerotiorum* sclerotia, thereby reducing the initial inoculum of the pathogen, in addition to improving chemical, physical, and biological characteristics of soil (VENTUROSOSO et al., 2013).

The potential use of dead cover in the management of soil-dwelling pathogens has already

been reported for *Rhizoctonia solani*, *Sclerotium rolfsii*, and *Pythium* spp. in pepper (HANSENA & KEINATH, 2013) as well as for *S. sclerotiorum* in soybean (*Brachiaria* used as dead cover) (GORGEN et al., 2009; 2010). However, few studies have evaluated the effectiveness of straws of winter cereals grown in southern Brazil as dead cover in the management of soybean white mold.

Thus, the objective of this study was to assess the optimum quantity and effectiveness of oat, rye, and triticale straws in the management of soybean white mold in the municipalities of Guarapuava and Palmas, Paraná, Brazil.

MATERIALS AND METHODS

Production of winter cereal straw

The experiments were conducted simultaneously in two municipalities of Paraná, Brazil, during the 2013–2014 harvest. The first experimental site is located in the municipality of Guarapuava (25°26'3.45"S, 51°39'24"W; 946 m MSL), and the second study site is located in the municipality of Palmas (26°27'49.67"S, 51°50'00.39"W; 1,247 m MSL). The climate of the municipalities is type Cfa (humid subtropical climate) according to the Köppen–Geiger classification. Mean annual temperature ranges between 16 °C and 20 °C, and mean rainfall is 1,880 mm per year (CUNHA et al., 2011).

Treatments included soybean cultivation in uncovered soil (control) and in soil covered with straw. The winter cereals used in the treatments were Embrapa 29 Garoa black oat (*Avena strigosa* Schreb.), BRS Serrano rye (*Secale cereale* L.), and BRS Saturno triticale (*X Triticosecale* Wittmack.).

The winter cereals were sown using 80 m² seeds, with a buffer of 17 cm between plantation rows. Phytosanitary treatment, soil correction, and fertilization followed the technical recommendations for crops (Mundstock, 1983). The experiment was conducted using a randomized block design, with seven replications, in 3 m × 10 m plots.

Samples of winter cereals from the central rows were collected manually, and plant height, fresh weight, and dry weight were measured. Dry weight was measured after drying the plants in an oven under forced air circulation at 65 °C for 72 hours. All measurements were obtained at the V11.1 vegetative stage, corresponding to the milky grain stage.

To evaluate treatment effects, analysis of joint variance was performed in a factorial arrangement with two sites (Guarapuava and Palmas) and four treatments, with means (winter cereals) compared by the Tukey test at 5% probability.

In vitro effects of winter cereal straws on the carpogenic germination of Sclerotinia sclerotiorum

Sclerotia were collected from soybean plants showing signs of white mold. These structures were surface sterilized (70% alcohol and 1% sodium hypochlorite for 60 seconds) and cultivated on a rice-based substrate to obtain the inoculum. The sclerotia produced on rice were selected according to size (2–3 cm) for further experiments.

The inhibition of carpogenic germination of *S. sclerotiorum* using straws of different winter cereals was evaluated on the basis of two factors; the first factor was based on high productivity reported in the literature, resulting in a yield of 10 t·ha⁻¹ (Meinerz et al., 2011), and the second factor was the actual yield obtained in field experiments (Guarapuava and Palmas).

The experiments were conducted in Gerbox plastic boxes containing the AA culture medium (water agar, 20 g·L⁻¹), on which 20 pre-sterilized sclerotia were inoculated. Subsequently, soil (4 mm layer) and cereal straws were placed carefully. The boxes were placed in a BOD incubator at 20 °C under a 12-hour photoperiod for 98 days. Evaluations were performed weekly by quantifying the formation of apothecia resulting from the carpogenic germination of sclerotia. The experiment followed a completely randomized design, with five replications of 20 sclerotia per box.

Effects of winter cereal straws in the management of soybean white mold under field conditions

The areas cultivated with winter cereals were desiccated (3.0 L·ha⁻¹ glyphosate) for sowing BMX Apollo soybean. Pre-sowing fertilization was performed using 100 kg·ha⁻¹ potassium chloride, and 200 kg·ha⁻¹ 8-20-18 NPK was added to plantation rows. The spacing between the rows was 50 cm, and the linear sowing density was 10 seeds per meter. From the R2 stage (full flowering) of soybean, the incidence of white mold was evaluated on the middle-third of the main stem, according to the methodology described by Guareschi et al. (2012). Disease severity was assessed based on a scale proposed by Juliatti et al. (2013). White mold incidence and severity were evaluated at the R5.1 (grains perceptible to touch, equivalent to 10% grain formation), R5.4 (51% to 75% grain formation), and R6 (full grain) stages.

Plant height and soybean yield were measured at harvest. Grain yield and 1000-grain weight were measured at 13% moisture, and values were adjusted to kg·ha⁻¹.

RESULTS AND DISCUSSION

Production of winter cereal straw

The associations between cultivation sites (Guarapuava and Palmas) and winter cereal production were examined based on plant height and dry weight. Rye presented higher plant height, followed by oat and triticale, in both municipalities (Table 1). A study by Meinerz et al. (2011) evaluating winter cereal development has highlighted rye for its greater height. The best height development was observed in Palmas, possibly due to the most optimum rainfall distribution during the experimental period in this region (data not shown). According to Rodrigues (2011), at the beginning of germination and emergence, plants require high water availability in the soil, which occurred in Palmas. The cumulative rainfall was 98 mm in Guarapuava and 171 mm in Palmas, possibly increasing the plants tolerance to bad weather throughout the growth period.

In Guarapuava, oat showed lower fresh and dry weights than triticale and rye; the fresh weight of rye was respectively 33.52% and 59.6% lower than that of triticale and rye (Table 1). The dry weights of oat were 7,840 and 15,611 kg·ha⁻¹ in Guarapuava and Palmas, respectively, and these values were higher than those reported by Demétrio et al. (2012) in five oat varieties (common black, IAPAR 61, IPR 126, FAPA, and FUNDACEP FAPA 43) in Santa Helena (average dry weight, 4,290 kg·ha⁻¹).

The dry weight of oat cultivated in Palmas was almost twice the value in Guarapuava. This may be because of lower temperature (by 1.8 °C) in Palmas than in Guarapuava. A low temperature favors the development of winter cereals, since it improve vernalization. Fontaneli et al. (2012) reported that rye showed higher fodder production (fresh weight) during colder periods due to the physiological characteristics of the plant, thus explaining the higher

rye fresh weight in Palmas. Meinerz et al. (2011) reported a greater increase in the fresh weight of rye than of oat, barley, and wheat. In our study, rye and triticale showed the highest straw production in the municipality of Guarapuava.

In vitro effects of winter cereal straws on the carpogenic germination of Sclerotinia sclerotiorum

Carpogenic germination was observed only in the control treatment (4 mm of soil cover on the sclerotia), and apothecia formation was observed at 37, 60, and 95 days after the start of the experiment (Table 2). Higher illuminance and aeration on the sclerotia in the absence of straw cover possibly created favorable conditions for apothecia formation, as described by Wu & Subbarao (2008).

The straw may or may not cover the soil, interfering with the illuminance necessary for germination. Venturoso et al. (2013) evaluated the effectiveness of various vegetation covers and reported that *Brachiaria* straw cover was highly effective because of its high dry weight. *B. ruziziensis* cover inhibited the formation of apothecia in tropical climate regions (GORGEN et al., 2009); although, the cultivation of this grass is not feasible in a region with low temperature, which impairs its development.

In treatments with winter cereal straws, the physical barrier formed was unfavorable for the carpogenic germination of sclerotia (Table 2). Similar results were observed by Silva et al. (2011), who reported that crop residues of oat, bean, vetch, and millet suppressed the carpogenic germination of *S. sclerotiorum* sclerotia.

Effects of winter cereal straws in the management of soybean white mold under field conditions

Evaluation of white mold incidence and severity revealed the associations between different areas and their history of winter cereal cultivation. In

Table 1 - Development of winter cereals in the municipalities of Guarapuava and Palmas, expressed as plant height (H), fresh weight (FW), and dry weight (DW).

Treatment	-----H (cm)-----		-----FW (kg·ha ⁻¹)-----		-----DW (kg·ha ⁻¹)-----	
	Guarapuava	Palmas	Guarapuava	Palmas	Guarapuava	Palmas
Oat	91.0 bB	106.5 bA	12.474 bB	19.502 aA	7.840 bB	15.611 aA
Rye	120.1 aB	132.3 aA	19.925 aA	20.680 aA	13.154 aA	16.028 aA
Triticale	89.6 cA	92.2 cA	18.765 aA	17.640 aA	12.302 abA	12.857 aA
CV (%)	7.42		21.37		25.89	

Different lower- and uppercase letters in columns and rows indicate significant differences (Tukey test, 5% probability).

Table 2 - Effects of winter cereal straws on the number of *Sclerotinia sclerotiorum* apothecia under controlled conditions in days (d) after the start of the experiment.

Treatments	-----Number of apothecia-----		
	37 d	60 d	95 d
Soil layer (4 mm)	10.4 a*	9.80 a	9.80 a
Triticale produced in Guarapuava (10 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Oat produced in Guarapuava (10 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Rye produced in Guarapuava (10 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Triticale produced in Guarapuava (6.46 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Oat produced in Guarapuava (4.63 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Rye produced in Guarapuava (6.77 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Triticale produced in Palmas (10 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Oat produced in Palmas (10 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Rye produced in Palmas (10 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Triticale produced in Palmas (7.72 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Oat produced in Palmas (5.57 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
Rye produced in Palmas (7.33 t·ha ⁻¹)	0.0 b	0.0 b	0.0 b
CV (%)	26.88	18.68	27.56

Means followed by the same letter do not differ significantly from each other (Tukey test, 5% probability).

Guarapuava, soybean cultivated on rye and triticale straws showed a lower white mold incidence at all stages (R5.1, R5.4, and R6). Meanwhile, soybean cultivated on oat straw showed the same white mold incidence as controls (without straw) (Table 3).

In Palmas, soybean cultivated on any winter cereal straw, specifically rye, showed a lower incidence of white mold than controls at the R5.1 and R5.4 stages (Table 4). The best performance of oat straw in controlling white mold in Palmas can be attributed to its greater straw yield in this region (15,611 kg·ha⁻¹) than in Guarapuava (7,840 kg·ha⁻¹).

The type of straw can influence disease incidence. Venturoso et al. (2013) evaluated the effectiveness of *Brachiaria* and sunflower cover

and reported that their use delayed the carpogenic germination of sclerotia by acting as a physical barrier and decreasing luminance.

In Palmas, compared with the control treatment (no straw), rye straw decreased white mold incidence by 92.3%, 88.4%, and 77.6% at the R5.1, R5.4, and R6 stages, respectively (Table 3). Successful sclerotia germination increases white mold incidence. The physical barrier provided by straw reduced illuminance, which may have affected carpogenic germination. In a study comparing sclerotia germination in the presence and absence of *B. ruziziensis* cover, Gorgen et al. (2009) reported a 98% reduction in the number of apothecia formed with the use of vegetation cover.

Table 3 - Incidence of white mold (%) on soybean at different phenological stages (R5.1, R5.4, and R6) when cultivated in soil covered with oat, rye, and triticale straws or in soil without cover in Guarapuava and Palmas.

Treatments	-----R5.1-----		-----R5.4-----		-----R6-----	
	Guarapuava	Palmas	Guarapuava	Palmas	Guarapuava	Palmas
No cover	1.4 bA*	1.2 bA	13.0 bA	15.0 bA	15.3 bA	23.5 cB
Oat	1.2 bB	0.3 aA	10.2 bA	7.3 abA	13.8 bA	13.1 bA
Rye	0.2 aA	0.1 aA	1.9 aA	1.7 aA	3.6 aA	5.2 aA
Triticale	0.2 aA	0.2 aA	2.5 aA	8.2 aA	4.8 aA	10.1 abB
CV (%)	17.23		18.87		28.11	

Different lower- and uppercase letters in columns and rows indicate significant differences (Tukey test, 5% probability).

Table 4 - Severity of white mold (%) on soybean at different phenological stages (R5.1, R5.4, and R6) when cultivated in soil covered with oat, rye, and triticale straws or in soil without cover in Guarapuava and Palmas.

Treatment	-----R5.1-----		-----R5.4-----		-----R6-----	
	Guarapuava	Palmas	Guarapuava	Palmas	Guarapuava	Palmas
No cover	32.3 bA	28.0 bA	89.4 bA	74.6 bA	90.5 bA	85.2 cA
Oat	16.4 aA	15.3 aA	64.0 abA	54.5 abA	78.9 abB	64.0 abA
Rye	27.0 bB	16.4 aA	82.0 abA	58.7 abA	88.4 abB	69.3 bA
Triticale	16.4 aA	13.2 aA	52.4 aA	40.7 aA	74.6 aB	54.5 aA
CV (%)	23.06		16.48		21.43	

Different lower- and uppercase letters in columns and rows indicate significant differences (Tukey test, 5% probability).

In Guarapuava and Palmas, white mold severity was reduced by respectively 2.3% and 18.6% using rye straw and by respectively 17.2% and 36.2% using triticale straw. In the absence of straw (control), disease severity was the highest (Table 4). Although, the use of straws reduced disease severity, it differed between the two study sites.

In Palmas, disease severity was the highest in the absence of cover at the R6 stage. In this area, soybean cultivated on winter cereal straws showed 60% lower disease severity than soybean cultivated without straw. In Guarapuava, disease severity was reduced by 76.5% and 68.7% using rye and triticale straws, respectively. Pereira & Blum (2010) have reported similar decreases in the incidence of other diseases, such as neck rot in common bean (*Sclerotium rolfsii*) cultivated on millet straw.

Another explanation of variations in disease severity across different sites may be the history of cultivation. In Palmas, forage turnip was previously used as cover. According to Brustolin et al. (2012), forage turnip is one of the hosts of white mold, and the presence of moisture due to rain or

mist is an important factor for sclerotia germination. These factors may affect the incidence and severity of white mold. According to Wu & Subbarao (2008), soil moisture is an important factor for sclerotium germination and apothecium development.

There were significant differences in plant height, 1000-grain weight, and grain yield between the two study sites, indicating regional effects on crop development. However, there were no associations between sites and individual treatment effects (Table 5).

In the absence of straw, plant height in Guarapuava was approximately 60% higher than that in Palmas, possibly due to the effects of temperature and high altitude on crop development. The 1000-grain weight was different between the two study sites, being higher in Palmas across all treatments (Table 5). This variation can be explained by different temperatures in the two regions. Palmas showed lower mean temperatures in December and January (2.13 °C and 1.16 °C, respectively) than Guarapuava, thus providing optimum conditions to achieve better physiological seed quality, which may

Table 5 - Plant height, 1000-grain weight, and crop yield of soybean grown in soil covered with different straws in Guarapuava and Palmas.

Treatments	-----Plant height (cm)-----		-----1000-grain weight(g)-----		-----Productivity (kg ha ⁻¹)-----	
	Guarapuava	Palmas	Guarapuava	Palmas	Guarapuava	Palmas
No cover	93.4 A*	58.7 B	156.7 B	195.4 A	3.2 A	3.4 A
Oat	94.6 A	60.9 B	162.1 B	192.1 A	3.3 A	3.7 A
Rye	95.7 A	67.3 B	163.9 B	194.9 A	3.8 A	3.9 A
Triticale	92.6 A	64.7 B	163.8 B	188.1 A	3.3 B	4.1 A
CV (%)	-----8.37-----		-----5.53-----		-----17.21-----	

Different lower- and uppercase letters in columns and rows indicate significant differences (Tukey test, 5% probability).

*There were no significant differences among treatments at the same cultivation site.

have reflected in grain weight in this region. Nunes et al. (2010) reported no differences in 1000-grain weight and yield between areas with soybean cultivation on *B. decumbens* and *B. brizantha* straws.

CONCLUSION

The vegetative development of winter cereals, such as oat, rye, and triticale, was affected by cultivation site (Guarapuava or Palmas). Under the experimental conditions, rye produced the highest dry weight. Under controlled conditions, winter cereal straws inhibited *S. sclerotiorum* apothecia formation.

Furthermore, soybean cultivated on rye, triticale, and oat straws showed a lower severity of white mold than soybean cultivated without vegetation cover. The use of rye and triticale straws reduced the incidence of soybean white mold in Guarapuava and Palma.

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DECLARATION OF CONFLICTS OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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