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Control of White Mold of Bean Caused by Sclerotinia sclerotiorum Using Organic Soil Amendments and Biocontrol Agents

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ABSTRACT

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Field studies were conducted near Lethbridge, Alberta, Canada during 1999-2001 to determine the effectiveness of residue-based organic soil amendments, with or without biocontrol agents, for suppression of carpogenic germination of sclerotia of *Sclerotinia sclerotiorum* and control of white mold of bean. Results of 3-year field experiments showed that soil amendment with certain organic substances such as sweet clover straw (2.5 tonnes/ha) or fish meal (0.8 or 2.5 tonnes/ha) reduced the carpogenic germination of sclerotia of *S. sclerotiorum* and thereby reduced the incidence and severity of white mold of bean. Further studies revealed that the addition of biocontrol agents such as *Coniothyrium minitans*, *Penicillium griseofulvum*, or *Trichoderma virens*, enhanced the suppressive effect of the organic soil amendments on *S. sclerotiorum*. The study concludes that amending soil with a mixture of organic soil amendment and biocontrol agent is a promising, environmentally sound method for management of white mold of bean.

Key words: *Sclerotinia sclerotiorum*, sclerotia, carpogenic germination, apothecia, soil amendment, biological control, *Coniothyrium minitans*, *Trichoderma virens*, *Penicillium griseofulvum*

INTRODUCTION

Sclerotinia sclerotiorum (Lib.) de Bary is a fungal pathogen that is distributed worldwide[3] and it has a broad host range[2], causing serious losses on many economically important crops[22]. Under certain environmental conditions, sclerotia, the overwintering bodies of *S. sclerotiorum*, can germinate carpogenically to produce apothecia[17] and release airborne ascospores for infection of bean (*Phaseolus vulgaris* L.)[16,25]. Thus, prevention of carpogenic germination of sclerotia in the soil is an effective strategy for reduction of inoculum potential of *S. sclerotiorum* and control of white mold of bean.

Disposal of agricultural by-products such as crop straws and animal manures has become an important environmental issue in modern agriculture. The use of residue-based organic amendments for control of soilborne plant diseases is one way to reduce the environmental hazards caused by agricultural wastes[12]. For instance, the liquid product CF-5, which is a fermented extract from agricultural wastes, suppresses carpogenic germination of sclerotia of *S. sclerotiorum* when applied to soil at rates

from 150 to 400 ppm, and enhances colonization of sclerotia by mycoparasitic fungi *Trichoderma* spp.[14] Another formulated compound, S-H mixture, which is made mainly of the agricultural wastes bagasse and rice husks and industrial waste[26], also inhibits *S. sclerotiorum* at rates from 1 to 2%[18]. Under controlled environments, soil amendment with some agricultural residues, such as fish meal, distiller's dry grain, canola straw, or sweet clover straw, at rates ranging from 0.5 to 3% (w/w) alone or in combination with fungal biocontrol agents was effective in the control of carpogenic germination of sclerotia of *S. sclerotiorum*[11]. Besides *S. sclerotiorum*, numerous studies showed that organic soil amendment was an effective strategy in the management of other diseases such as control of Rhizoctonia damping-off of cabbage using SSC-06, a container medium amended with spent forest mushroom compost[13], or using the commercial product FBN-5A[24] and control of Fusarium diseases of crops using S-H mixture[26].

Biological control is another strategy that has been suggested as a way to control diseases caused by *S. sclerotiorum*[7]. Mycoparasites such as *Coniothyrium minitans* Campbell[4,5] or *Trichoderma virens* (Miller et al.) von Arx[6] can effectively kill sclerotia of *S. sclerotiorum* in soil. Other fungi, such as *Penicillium griseofulvum* Dierckx, can produce antibiotics that suppress growth of other fungi[21]. Studies conducted in western Canada revealed that treatment of soil with *C. minitans* resulted in reductions in carpogenic germination of sclerotia of *S. sclerotiorum* under the canopies of host crops such as bean and pea (*Pisum sativum* L.)[8] or canola (*Brassica napus* L.) and safflower (*Carthamus tinctorius* L.)[10], as well as non-host crops such as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.)[20]. A study comparing different methods of application of *C. minitans* (foliar spray, soil amendment, and foliar spray plus soil amendment) found that the treatment of foliar spray plus soil amendment with *C. minitans* was as effective as treatment with the fungicide benomyl, in reducing incidence of white mold of bean[9].

The objective of this study was to determine the effectiveness of applying organic soil amendments alone, or in combination with fungal biocontrol agents, for suppression of carpogenic germination of sclerotia of *S. sclerotiorum* and control of white mold of bean under field conditions.

MATERIALS AND METHODS

Field experiments were conducted during 1999-2001 at the Agriculture and Agri-Food Canada Lethbridge Research Centre (LRC) near Lethbridge, Alberta, Canada, to test eight organic residues for suppression of carpogenic germination of sclerotia of *S. sclerotiorum* and control of white mold of common bean. The organic residues were selected from a previous study[11] and had varying effects on carpogenic germination of sclerotia of *S. sclerotiorum* under controlled conditions. They were bone meal, canola (cv. Westar) straw, cattle manure (raw), cattle manure (actively composted for 84 days), cattle manure with wood chips (actively composted for 84 days), distiller's dry grain, fish meal, and sweet clover (*Melilotus officinalis* L.) (cv. Norgold) straw. Canola and sweet clover straws were collected by harvesting the above-ground plant material at anthesis from demonstration plots at the Agriculture and Agri-Food Canada Lethbridge Research Centre (LRC) at Lethbridge, Alberta, Canada. Straws were dried in an oven at 55°C for 14 days, ground using a Thomas-Wiley® laboratory mill, model #4 (Thomas Scientific, Philadelphia, PA, USA), and sieved through a mesh screen with 2 mm square openings. Cattle manures were collected from the feedlot and composting facilities at LRC, and were dried, ground and sieved using the same procedure as for crop straws. Actively composted manures were turned at day 14, 21, 29, 50, 70 and 84 of the composting process. Bone meal was obtained from Green Valley Fertilizer, Abbotsford, British Columbia, Canada; fish meal was from Unifeed, Lethbridge, Alberta, Canada; and distiller's dry grain was from Black Velvet Distilling Co., Lethbridge, Alberta, Canada. Bone meal, fish meal, and distiller's dry grain were already in dried, ground form when acquired.

Sclerotia of *S. sclerotiorum* isolate LRC 2148 were produced by growing the pathogen on a processed bean substrate. Canned red kidney beans (Fraser Valley Foods; Fraser Valley, British Columbia, Canada) were dispensed into sterile 250 mL clear plastic dishes (Twinpak, Regina, Saskatchewan, Canada), with 25 mL per dish. To each dish, four PDA plugs (5 mm diameter) of 5-day-old mycelial mats of *S. sclerotiorum* were added, and the dishes were kept at 10°C in the dark for 10 weeks. Sclerotia produced on the colony in each dish were harvested by washing in distilled water, and were air-dried overnight on paper towel. Sclerotia with a diameter of 5 to 10 mm were selected and stored at 10°C for approximately two weeks prior to use for the field study.

Experiments were conducted in an irrigated field using the viny, small red bean cultivar NW63. In each year, the experiment was conducted in a part of the field that was fallowed in the previous year. Before seeding, the field was fertilized with nitrogen (34-0-0; N-P-K) at the rate of 200 kg/ha. The experimental area was staked out into plots, 3.5 m long by 2 m wide, in a randomized complete block design with four replicates. The soil in each plot was amended by spreading dried, ground organic

residues on the soil surface at a rate of 2.5 tonnes/ha for all of the residues, except for the treatment of cattle manure with wood chips, which was applied at the rate of 3.3 tonnes/ha, and the treatment of canola straw, which was applied at rates of 2.5 or 0.8 tonnes/ha. Residues were immediately mixed into the soil to a depth of 8 cm using a garden rototiller (Troy-Bilt, Troy, NY, USA). Bean seeds were planted into amended and non-amended plots at the seeding rate of 229 kg/ha on 21 May 1999, 25 May 2000, and 23 May 2001, with seeding depth of 2.5 cm and row spacing of 22.5 cm.

After seedling emergence, sclerotia were buried at the depth of 2 cm in every other space between rows, with 100 sclerotia spread evenly over the 3.5 m row length. Bean plots infested with sclerotia but without organic soil amendment, and bean plots without sclerotia or organic soil amendment, were used as controls. The bean crop was irrigated frequently from the late vegetative stage to the late pod-filling stage, to provide soil moisture conditions conducive for apothecial development. From late bloom (early August) to maturity (mid September), data on the number of carpogenically germinated sclerotia were collected weekly. Colour-coded sticks were used to mark germinated sclerotia that were previously counted, allowing cumulative counts of results. At the late pod-filling stage (early September), plants were rated for incidence and severity of white mold by visual observation of symptoms[22]. The six middle rows of each plot were rated, ignoring the 0.5 m on each end of each row. Each plant was rated on a scale of 1-4, where 1=healthy, 2=single stem infected, 3=multiple stems infected, and 4=dead plant. Disease incidence was defined as the percentage of plants infected by *S. sclerotiorum*. Disease severity was calculated as a weighted average of the plant ratings, $DS = \Sigma nr/t$, where DS = disease severity (ranging from 1 - 4), n = number of plants, r = disease rating (1 - 4), and t = total number of plants rated.

A second field study was conducted in 2000 and 2001 to assess the effectiveness of control of white mold of bean by soil amendment with organic residues plus an added microbial (biocontrol agent) component. The biocontrol agents were: *Coniothyrium minitans* isolate LRC 2137, *Trichoderma virens* isolate LRC 2425, and *Penicillium griseofulvum* isolate LRC 2461. Inocula of the biocontrol agents were prepared by growing each organism on a mixture of wheat bran and corn meal. Aluminum trays (23 x 29 x 6.5 cm, W x L x H) were filled with a mixture of 150 g each of wheat bran and corn meal, and 300 ml of distilled water. Trays were covered with aluminum foil and autoclaved twice with 48 hrs between sterilization cycles. Biocontrol agents were grown on PDA at room temperature (20±2°C) under continuous fluorescent light for three weeks. Agar plugs (8 mm diameter) were removed from the colony margin using a cork borer, and 20 agar plugs were evenly placed on the surface of the wheat bran - corn meal mixture. Trays were kept at 20°C for three weeks, and stirred weekly during that time, to encourage complete colonization of the substrate. The resulting inoculum was air-dried and ground to 1 mm particle size using a Thomas-Wiley® laboratory mill (see above). The combined microbial inoculum and composted material were prepared by mixing each of the biocontrol agents with 84-day-old composted wood chip cattle bedding, or 84-day-old composted wheat straw cattle bedding. The ratio of biocontrol agent and compost was 2:3 (w/w). The resulting fungus-compost mixtures were applied to field plots at the rate of 2.5 tonnes/ha, and tested using the same methods described for the previous field study.

Within each study, differences between treatments in percent carpogenic germination of sclerotia of *S. sclerotiorum*, disease incidence, and disease severity of dry bean were analyzed for statistical significance using analysis of variance at the P=0.05 level. Separation of means was done using Duncan's multiple range tests. For percent carpogenic germination of sclerotia, the data were converted using a log transformation for the analysis. All statistical analyses were conducted using SAS/STAT® software version 6[23].

RESULTS

For all field experiments during 1999-2001, the sclerotia of *S. sclerotiorum* buried in the plots germinated carpogenically to produce tan-coloured apothecia at the soil surface soon after the bean canopy closed over the inter-row spaces in late July. Sclerotia continued to produce apothecia during the month of August and into early September, when the growing season ended. During the counting of germinated sclerotia, the release of ascospores from apothecia in the form of airborne spore clouds was often observed when the canopy was carefully opened.

In the first study, soil treatment with any of the eight tested agricultural residues resulted in significant (P<0.05) reductions in carpogenic germination of sclerotia of *S. sclerotiorum* in 1999 and 2000, compared to the untreated control (sclerotia alone) (Table 1). In 2001, only the treatments of sweet clover straw or fish meal significantly reduced carpogenic germination of sclerotia. Soil treatment with fish meal was effective at both rates of 0.8 and 2.5 tonnes/ha in all three years. The frequencies of carpogenic germination in plots treated with sweet clover straw were 9, 5 and 12% for 1999, 2000, and 2001,

Table 1. Effect of soil amendment with agricultural residues on carpogenic germination of sclerotia of *Sclerotinia sclerotiorum* (field experiments, 1999-2001).

Treatment	Germinated sclerotia (%)		
	1999	2000	2001
Control (with sclerotia)	47 a[1]	41 a	25 a
Control (without sclerotia)	-	-	-
Raw cattle manure 2.5 t/ha	27 b	16 bc	17 abc
Wood chip compost 3.3 t/ha	-[2]	18 b	14 abcd
Composted cattle manure 2.5 t/ha	17 cd	8 de	25 a
Bone meal 2.5 t/ha	19 c	11 cd	20 ab
Canola straw 2.5 t/ha	11 de	11 cd	17 abc
Distiller's dry grain 2.5 t/ha	13 de	6 def	16 abcd
Sweet clover straw 2.5 t/ha	9 e	5 def	12 bcde
Fish meal 0.8 t/ha	7 ef	10 d	6 cde
Fish meal 2.5 t/ha	2 fg	2 ef	4 de
Significance (F)	.0135	.0168	.0316

[1] Means within a column followed by the same letter are not significantly different (P<0.05; Duncan's multiple range test).
[2] Wood chip compost was not tested in 1999.

respectively, compared to 47, 41, and 25% for the untreated controls.

Soil treatment with any of the tested residues also resulted in significantly (P<0.05) lower disease incidences in 1999 and 2000, compared to the untreated control (sclerotia alone) (Table 2). Only the treatment of 2.5 tonnes/ha fish meal resulted in significant reduction of disease incidence in 2001. For example, the disease incidences for the treatment of 2.5 tonnes/ha fish meal were 14, 3, and 10% for 1999, 2000, and 2001, respectively, compared to 71, 48, and 19% for the untreated controls. A similar trend was observed with respect to disease severity, with all of the treatments significantly (P<0.05) reducing disease severity in 1999 and 2000, but not in 2001 (Table 2). Disease severity indices for the treatment of 2.5 tonnes/ha fish meal were 1.2, 1.0 and 1.2 for the three years, compared to 2.5, 1.7, and 1.5 for the untreated controls. Incidence of white mold was low (less than 19%) for all treatments of the experiment in 2001.

In the second field study using soil amendment with microbially enhanced mixtures, significant (P<0.05) reductions in carpogenic germination of sclerotia of *S. sclerotiorum* were observed for all treatments in 2000 (Table 3). These were accompanied by significant reductions in incidence and severity of white mold of bean for the treatments of *T. virens* + composted wood chips, *C. minitans* + composted wheat straw, and *C. minitans* + composted wood chips in 2000 (Table 4). In 2001, the treatments *of P. griseofulvum* + composted wood chips and *T. virens* + composted wood chips significantly (P<0.05) reduced carpogenic germination of sclerotia of *S. sclerotiorum* (Table 3), but no differences were observed in white mold incidence or severity in 2001 (Table 4) due to low disease levels.

DISCUSSION

This study demonstrates that soil amendment with certain agricultural residues is effective in controlling carpogenic germination of sclerotia of *S. sclerotiorum* in the field, and thereby reducing the incidence and severity of white mold of bean caused by this pathogen. The study also suggests that some agricultural residues that were previously thought of as wastes, such as crop straws are actually valuable commodities that can be used to improve pulse crop production. Use of organic soil amendments can therefore enhance the environmental sustainability of crop production by reducing the need for disease control by chemical fungicides, while simultaneously assisting in proper disposal of agricultural residues.

In this study, carpogenic germination of sclerotia of *S. sclerotiorum* was lower in 2001 than in other years, and thus the incidence and severity of white mold were also lower in 2001. For example, the frequency of carpogenic germination of sclerotia of *S. sclerotiorum* for the untreated control (sclerotia alone) was 25% in 2001, compared to 47 and 41% in 1999 and 2000, respectively (Table 1). The incidence of white mold for the untreated control (sclerotia alone) was 19% in 2001, compared to 71 and 48% in 1999 and 2000, respectively, and the severity of white mold for the untreated control (sclerotia alone) was 1.5 in 2001, compared to 2.5 and 1.7 in 1999 and 2000, respectively (Table 2). Certain conditions such as high soil moisture and cool soil temperatures (10-25℃) are conducive factors for carpogenic germination of sclerotia of *S. sclerotiorum* and subsequent development of

Table 2. Effect of soil amendment with agricultural residues on control of white mold of dry bean (field experiments, 1999-2001).

Treatment	Disease incidence (%)			Disease severity[1]		
	1999	2000	2001	1999	2000	2001
Control (with sclerotia)	71 a[2]	48 a	19 ab	2.5 a	1.7 a	1.5 ab
Control (without sclerotia)	39 cd	31 b	3 c	1.7 bcd	1.4 b	1.0 c
Raw cattle manure 2.5 t/ha	53 b	9 cd	21 ab	2.0 b	1.1 c	1.6 ab
Wood chip compost 3.3 t/ha	-[3]	16 c	17 ab	-	1.2 c	1.4 abc
Composted cattle manure 2.5 t/ha	47 bc	8 cd	18 ab	1.9 bc	1.1 c	1.4 abc
Bone meal 2.5 t/ha	38 cd	7 cd	25 a	1.6 cde	1.1 c	1.6 ab
Canola straw 2.5 t/ha	23 ef	7 cd	13 abc	1.3 f	1.1 c	1.3 abc
Distiller's dry grain 2.5 t/ha	35 cde	6 cd	26 a	1.6 de	1.1 c	1.7 a
Sweet clover straw 2.5 t/ha	28 de	3 d	16 abc	1.5 ef	1.0 c	1.3 abc
Fish meal 0.8 t/ha	24 ef	6 cd	13 abc	1.4 ef	1.1 c	1.4 abc
Fish meal 2.5 t/ha	14 f	3 d	10 bc	1.2 f	1.0 c	1.2 bc
Significance (F)	.0027	.0155	.0388	.0208	.0018	.0154

[1] Severity index: 1=healthy, 2=single stem infected, 3=multiple stems infected, 4=dead.
[2] Means within a column followed by the same letter are not significantly different ($P<0.05$; Duncan's multiple range test).
[3] Wood chip compost was not tested in 1999.

Table 3. Effect of soil amendment with microbial enhanced compounds on carpogenic germination of sclerotia of *Sclerotinia sclerotiorum* (field experiments, 2000 and 2001).

Treatment	Germinated sclerotia (%)	
	2000	2001
Control (with sclerotia)	44 a[1]	23 a
Control (without sclerotia)	-	-
Penicillium griseofulvum + composted wheat straw	11 bc	22 ab
Penicillium griseofulvum + composted wood chips	13 b	8 bc
Trichoderma virens + composted wheat straw	11 bc	14 abc
Trichoderma virens + composted wood chips	10 bc	8 bc
Coniothyrium minitans + composted wheat straw	4 bcd	17 ab
Coniothyrium minitans + composted wood chips	3 cd	13 abc
Significance (F)	.0307	.0250

[1] Means within a column followed by the same letter are not significantly different ($P<0.05$; Duncan's multiple range test).

Table 4. Effect of soil amendment with microbial enhanced compounds on control of white mold of dry bean (field experiments, 2000 and 2001).

Treatment	Disease incidence (%)		Disease severity[1]	
	2000	2001	2000	2001
Control (with sclerotia)	37 ab[2]	33 a	1.5 ab	1.8 ab
Control (without sclerotia)	41 a	9 a	1.6 a	1.1 b
Penicillium griseofulvum + composted wheat straw	15 bc	29 a	1.2 bc	1.7 ab
Penicillium griseofulvum + composted wood chips	20 abc	18 a	1.3 abc	1.4 ab
Trichoderma virens + composted wheat straw	14 bc	19 a	1.2 bc	1.3 ab
Trichoderma virens + composted wood chips	9 c	36 a	1.1 c	1.9 a
Coniothyrium minitans + composted wheat straw	8 c	37 a	1.1 c	1.9 a
Coniothyrium minitans + composted wood chips	7 c	24 a	1.1 c	1.6 ab
Significance (F)	.0003	.0539	.0007	.0152

[1] Severity index: 1=healthy, 2=single stem infected, 3=multiple stems infected, 4=dead.
[2] Means within a column followed by the same letter are not significantly different ($P<0.05$; Duncan's multiple range test).

white mold of bean[(1)]. However, in 2001, the month of August was exceptionally hot and dry at LRC, with soil temperatures at 5 cm depth ranging from 26 to 34°C, and air temperatures ranging from 21 to 38°C. Although the bean plots were irrigated frequently to maintain high soil moisture, these extreme temperatures likely interfered with the normal disease development process. In addition, the high temperatures resulted in deterioration of the bean

crop canopy in some plots, and this may have further reduced carpogenic germination of sclerotia and development of white mold.

Huang and Janzen[15] reported that soil amendment with urea was effective in suppression of production of apothecia from sclerotia of *S. sclerotiorum* and the volatile substances released from decomposition of urea, such as ammonia, were responsible for the suppressive effects on this pathogen. Janke et al.[19] found that ammonia was toxic to mycelial growth of *S. sclerotiorum* at the high concentration of 800 ppm, but could be stimulatory to mycelial growth at the lower rate of 200 ppm. Huang et al.[11] also suggested that *in vitro* suppression of carpogenic germination of sclerotia of *S. sclerotiorum* by the same organic soil amendments used in the current study was due to production of ammonia during decomposition. In the current field study, it is likely that the liberation of ammonia from decomposition of organic soil substrates such as fish meal or crop straws is at least partially responsible for suppression of carpogenic germination of sclerotia of *S. sclerotiorum.* Thus, selection of plant tissues that are rich in nitrogen such as legume crops may enhance release of ammonia during decomposition in the soil and enhance the control of soilborne pathogens. Further research would be useful to determine optimal application rates for the organic soil amendments, and to understand the factors that determine the rate of ammonia liberation such as soil moisture, temperature, microbial activity, and other factors. In addition, there may be other substances released during decomposition of organic soil amendments that are toxic to plant pathogens, and these should be characterized.

The incorporation of biocontrol agents into organic soil amendment formulae provides a means by which the effectiveness of soil treatments can be enhanced. The organic residue components of such mixtures provide an initial attack on sclerotia of *S. sclerotiorum* by generation of toxic ammonia during decomposition. Any surviving sclerotia face a second line of attack, provided by mycoparasitic fungi that are incorporated into the mixture. Janke et al.[19] found that *S. sclerotiorum* was more sensitive to ammonia than some other fungi. However, the ammonia sensitivity of the biocontrol fungi used for this study (*C. minitans*, *T. virens* and *P. griseofulvum*) is unknown. If mycoparasites of *S. sclerotiorum* with high ammonia tolerance can be identified, then it is likely that the effectiveness of this method can be further enhanced. By providing two avenues of control of sclerotia of *S. sclerotiorum*, it is likely that inoculum of the disease can be more effectively and efficiently managed in the field, contributing to the long-term management of sclerotinia diseases in crops.

Decomposition of agricultural residues in the soil has the potential to provide valuable nutrients for the developing crop. Although this aspect of organic soil amendments was not part of the current study, no negative (phytotoxic) effects for the tested materials on the bean crop were observed. Further development of the organic soil amendment formulae could examine whether the substances used have growth-promoting properties. It is feasible that a properly formulated organic soil amendment might reduce the need for fertilizer inputs for crop production, in addition to reducing the need for chemical fungicides. Thus, organic soil amendments with properly selected materials would have the potential for control of plant disease, improvement of soil fertility and improvement of environmental sustainability.

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摘 要

黃鴻章[1,3]、Erickson, R. S.[1]、張治[1]、Moyer, J. R.[1]、Larney, F. J.[1]、黃振文[2]. 2005. 利用有機土壤添加物與拮抗菌防治菜豆菌核病. 植病會刊 14:183-190. ([1] 加拿大農業及農業食品部 Lethbridge 研究中心; [2] 國立中興大學植物病理系; [3] 聯絡作者，電子郵件：huangh@agr.gc.ca，傳真：+1-403-382-3156)

西元 1999 至 2001 年間於加拿大亞伯達省 Lethbridge 附近進行田間試驗，評估有機土壤添加物添加拮抗菌與否對於抑制菌核病菌子囊盤形成與防治菜豆菌核病的效果。三年的田間試驗結果顯示，土壤中施用含有甜苜蓿 (2.5 噸/公頃) 或魚粉 (0.8 或 2.5 噸/公頃) 有機資材的土壤添加物可降低菌核病菌形成子囊盤，進而有效降低菌核病的發病率與發病度。進一步研究發現有機土壤添加物加入拮抗菌如 *Coniothyrium minitans*、*Penicillium griseofulvum* 或 *Trichoderma virens* 等可促進添加物的抑菌效果。本研究說明土壤施用含拮抗菌之有機土壤添加物是一項符合環境友好的菜豆菌核病防治方法。

關鍵詞：菌核病菌、菌核、子囊盤、土壤添加物、生物防治、 *Coniothyrium minitans*、*Trichoderma virens*、*Penicillium griseofulvum*