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Biological Control of Banana Anthracnose

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ABSTRACT

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Nutrient yeast extract-dextrose agar (NYDA) appeared to be the most effective for isolating bacteria and yeast from extract of green banana peel quantitatively and qualitatively in compare to Acidified potato dextrose agar (APDA), and Banana peel extract agar (BPEA). Peel extract of green banana was cultured in Carrot nutrient solution supplemented with nystatin (CNA) or Carrot nutrient solution supplemented with streptomycin-chloramphenicol (SMY) at 25 C for 3 days, the number of bacterium increased 10^5–10^8-fold and yeast increased about 10^5–10^6-fold, however, colony types of bacteria and yeast decreased. For isolation of bacteria and yeast with NYDA, 412 isolates of bacterium and 217 isolates of yeast were obtained from green banana fruit collected from western Taiwan. Inoculation test showed that only 4 bacterial isolates and 5 yeast isolates were consistently effective to inhibit anthracnose lesion expansion on ripe banana fruit by 22%-43% and 32%-42%, respectively. The inhibitory effect to anthracnose lesion expansion increased with increasing concentration of biocontrol agents tested, but decreased with increasing spore concentration of the pathogen. However, these antagonists at a concentration up to 10^8 cells/ml were not able to inhibit spore germination of the pathogen. For control of banana anthracnose from natural infection, one isolate of bacterium and two isolates of yeast were able to reduce lesion numbers on banana fingers consistently.

Key words: banana anthracnose, biological control, *Colletotrichum musae*.

INTRODUCTION

Postharvest losses in fruit caused by fungal decay are serious problems during storage and shipment. Application of fungicides is by far the most effective method to control postharvest diseases (9). However, the development of resistance to many fungicides by major postharvest pathogens and health risk concerns over synthetic pesticides in food and the environments have created interest in alternative approaches for control of postharvest diseases (10,12,19,20,25,26). Fungal and bacterial antagonists, investigated as alternative fungicides, have been found effective for the control of various postharvest diseases (2,4,11,13,14,17, 22,23,27). Reliability and economic are two major factors that will determine the feasibility of any biocontrol system (10). Successes in biocontrol of postharvest diseases can be attributed to highly reproducible results under controlled storage conditions (25). Therefore, biological control of postharvest pathogens of fruit is a rapidly developing and relatively new area of research in compared to biological control of pathogens on other plant parts (26).

Banana is the most important export fruit in Taiwan. Banana anthracnose induced by *Colletotrichum musae* (Berk. & Curt.) von Arx, is an important postharvest disease and causes serious loss during transport (18). To control this postharvest disease, the application of fungicides is routinely performed. However, the development of fungicide resistant strains of the pathogen has been documented (24). In addition, the adverse effects of fungicide residues in fruit to consumers have caused public concerns in Japan market (Personal communication). Thus, there is an urging need to develop alternative methods for control of the pathogen. In the present study, we screened antagonistic bacteria and yeast against *C. musae* and evaluated efficiency of these antagonists for control of the disease caused by the pathogen.

MATERIALS AND METHODS

Isolation of microorganisms

Green banana fruits were collected from banana plantations in western Taiwan periodically and transferred back to laboratory. The fruits were washed with tap water and blotted with a tissue paper. Pieces (*ca.* 1 cm^2) of banana peels were cut with a sterile scalpel and placed in a flask containing 25 ml sterile distilled water. Flask containing four pieces of banana peels was shaken with a vortex for 3 min. To isolate microorganisms, serial dilutions of aqueous suspensions were plated on various media, including water agar supplemented with banana peel extract (BPEA) (10% peel extract, 2% agar), acidified potato dextrose agar (APDA) (39 g Difco PDA, 1000 ml distilled water, pH 3.8), nutrient-yeast extract-dextrose agar (NYDA) (16). Peel extract was also enriched in carrot nutrient solution (500 ml carrot extract, 0.05 g KNO_3, 0.05 g K_2HPO_4, 0.025 g $MgSO_4 \cdot 7H_2O$, 0.05 g $CaCO_3$) supplemented with 500 ppm nystatin (CNA) or 500 ppm streptomycin-500 ppm chloramphenicol (SMY) at 25 C for 3 days and then plated on NYDA. Separate colonies with different colony type on agar plates were transferred to pure cultures.

To isolate and screen as many different microorganisms as possible, a taxonomic identification of these organisms was not carried out.

Screening for antagonistic activity *in vitro*

As the antagonistic activity of bacteria, but not yeast, against postharvest pathogens is through antibiotic production (3,8,21,22), only bacteria were tested *in vitro* for screening potential antagonists. Bacteria were screened on PDAY (potato dextrose agar supplemented with 0.1% yeast extract) by using dual culture. Bacterial isolate was streaked as a cell suspension onto plates 2 cm from the edge. The inoculated plates were incubated at 25 C for 48 hr, and subsequently a filter paper disc (6 mm in dia.) containing mycelia of the pathogen was placed onto the same plate 2 cm from the edge in opposite side. These plates were transferred back to 25 C for another 10 days for evaluating antagonistic activity. Isolates that reduced pathogen development by producing a demarcation zone were selected.

Screening for antagonistic activity *in vivo*

Bacteria and yeast grown on PDAY at 25 C for 3 days were suspended in sterile distilled water. The cell concentration was determined and adjusted to 10^8 cells/ml. Ten isolates of each kind of bacteria and yeast were mixed separately by equal volume for the first test.

The *in vivo* tests were carried out on ripe banana fruit (Giant Cavendish). The fruits were obtained from market, washed in water, and blotted in a tissue paper. Washed fruits were wounded as a hole (*ca.* 2 mm × 2 mm × 2 mm). Each wound was treated with 20 μl of mixed cell suspension of bacteria or yeast 1–2 hr prior to applying 20 μl spore suspension. Spore suspension of the pathogen was obtained from 2-week-old PDA cultures by flooding the tubes with 5 ml sterile distilled water and adjusted to 10^5 spores/ml. The wounds treated with sterile distilled water were served as control. Inoculated fruits were incubated in a moist chamber at 25 C. Rot development was determined by measuring the lesion diameter and the reduction induced by the antagonists was determined 7 days after incubation. Five wounds were used for each treatment and the experiments were done 3 times. Again, each isolate in the effective combination was tested separately as the same procedures described above. The efficacy of each bacterial and yeast antagonist for control of lesion development of banana anthracnose was tested at different cell (spore) concentration of antagonists and pathogen. Each treatment was repeated with 7 fruits and the experiment was done 2 times.

Inhibition of spore germination of the pathogen

The concentration of antagonists and pathogen were adjusted to 10^5–10^8 cells/ml and 10^3–10^6 spores/ml, respectively. Equal volume of cell suspension was mixed and placed onto water agar evenly. Spore germination and appressorium formation of the pathogen were determined after incubating the plates at 25 C for 24 hr.

Control of anthracnose disease

Mature green fruits obtained from Taiwan Fruit Cooperative were transferred to laboratory. Hands of banana were cut into single finger. The fingers were washed with tap water and blotted in a tissue paper. Subsequently, the fingers were dipped in cell suspension (10^8/ml) of antagonist for about 1–2 min. After air-dry, the fruits were ripened by injecting 1000 ppm ethylene at 20 C for 24 hr. The ripening fruits were placed on the table at room temperature for observing the development of anthracnose lesion.

In other experiment, banana fruits were covered with blue plastic bags at shooting and inoculated with the pathogen (10^4 spores/ml) 3–4 weeks after flowering, followed by spraying antagonists (10^8 cells/ml) to the inoculated fruits 2 days later. After harvest, the hands from each treatment were cut into single finger and divided into two parts. One part was immersed in the antagonist suspension same as used in the field, the other part was not. The ripening fruits were placed at room temperature for observing anthracnose development.

TABLE 1. Effect of different medium[1] on bacterial population isolated from banana peel

Banana sample	cfu/cm^2		
	NYDA	BPEA	CNA
1	1.5×10^4	1.1×10^4	1.6×10^{11}
2	1.0×10^6	1.8×10^5	1.5×10^{11}
3	6.5×10^4	3.5×10^4	1.8×10^{11}
4	1.8×10^3	1.5×10^3	1.8×10^{11}
5	6.5×10^4	6.8×10^4	1.6×10^{11}

[1] NYDA : Nutrient-yeast extract-dextrose agar,
BPEA : Banana peel extract agar,
CNA : Carrot nutrient solution supplemented with nystatin.

TABLE 2. Effect of different medium[1] on yeast population isolated from banana peel

Banana sample	cfu/cm^2			
	NYDA	BPEA	APDA	SMY
1	325	175	200	—[2]
2	1750	75	500	—
3	2500	175	575	3.2×10^8
4	2500	75	1825	3.7×10^8
5	750	3250	1750	3.7×10^9

[1] NYDA : Nutrient-yeast extract-dextrose agar,
BPEA : Banana peel extract agar,
APDA : Acdified PDA,
SMY : Carrot nutrient solution supplemented with streptomycin-chloramphenicol.
[2] —: Not tested.

TABLE 3. Source of antagonists effective to control banana anthracnose

Isolate	Origin	Lesion Inhibition (%)
Bacterium		
TN-S221	Tainan (Shinyen)	11.3–50.5 (33.9)[1]
TN-Y21	Tainan (Ensui)	16.8–46.0 (35.5)
TN-Y511	Tainan (Ensui)	28.5–50.8 (42.9)
TP-Tu311	Taipei (NTU)	16.2–28.5 (22.1)
Yeast		
Y11-1	Taipei (NTU)	17.2–42.7 (31.6)
Y11-2	Taipei (NTU)	22.9–38.1 (31.9)
Y23-10	Pingtung (LiKang)	23.5–51.0 (41.0)
Y24-7	Pingtung (LiKang)	23.5–54.3 (41.3)
Y24-8	Pingtung (LiKang)	30.4–51.3 (42.0)

[1] Number in parentheses represented the average of three experiments, five replications were used for each experiment.

RESULTS

Isolation and screening

Isolation of bacteria from surface of green banana varied greatly with different media used, and bacterial population might varied in different samples, ranging 10^3–10^6 cells/cm^2 of banana peel (Table 1). Density of bacteria isolated from peel surface with NYDA was higher than that with BPEA. However, bacteria could not be grown on APDA, since no colony formed on APDA. When peel extract was incubated in CNA at 25 C for 3 days, the density of bacteria might reach to 1.5–1.8×10^{11}/cm^2, in spite of different samples used; the bacterial density increased 10^5–10^8-fold, compared to that on NYDA. Although bacterial population significantly increased in CNA, numbers of colony types decreased.

Isolation efficiency of yeast from peel extract of green banana also varied in media used and in fruit samples obtained (Table 2). NYDA was the most effective medium to isolate yeast, followed by APDA, but BPEA was the least effective. Yeast population on the surface of green banana ranged from 10^2 to 10^3 per cm^2 which was much lower than bacterial population on peels. Again, when peel extract was incubated in SMY at 25 C for 3 days, the yeast population increased 10^5–10^6-fold and reach to 10^8/cm^2.

By using NYDA, 412 isolates of bacteria and 217 isolates of yeast were obtained from green banana fruits collected from banana plantations. These isolates were tested *in vitro* and *in vivo* for antagonistic activity. Of these, 4 bacterial and 5 yeast isolates consistently inhibited lesion expansion of banana anthracnose (Table 3). These bacterial isolates obtained from Tainan and Taipei were able to reduce lesion size by 22.1%–42.9%. Antagonistic yeast obtained from Taipei and Pingtung reduced lesion size by 31.6%–42.0%.

Effect of antagonists on spore germination of the pathogen

All antagonists at a concentration of 10^6–10^8 cells/ml were not able to inhibit spore germination of the pathogen on water agar (Table 4). Inhibition of appressorium formation from germinated spores varied at different antagonists tested (Table 5). Appressorium formation was significantly reduced by antagonistic bacterial isolates TN-S221, TN-Y511, and yeast isolates Y11-1, Y11-2, Y24-7 and Y24-8. While bacterial isolates TN-Y21 and Tp-Tu311 and Yeast isolate Y23-10 inhibited appressorium formation at low concentration of antagonists tested, but enhanced appressorium formation at high concentration of antagonists tested. Although appressorium formation was enhanced by antagonists, all appressoria became hyaline and swell.

TABLE 4. Conidial germination of *Colletotrichum musae* affected by different antagonistic concentration

Antagonist	Germination (%)		
	10^6	10^7	10^8
Bacterium			
TN-S221	97.4	92.5	88.4
TN-Y21	98.7	—[1]	97.4
TN-Y511	99.3	99.7	97.4
TP-Tu311	100.0	98.8	98.3
Yeast			
Y11-1	99.0	97.4	—
Y11-2	100.0	98.0	100.0
Y23-10	100.0	100.0	99.7
Y24-7	100.0	99.7	100.0
Y24-8	99.7	63.5	—
Control	100.0	100.0	100.0

[1] —: Not tested.

TABLE 5. Appressorium formation of *Colletotrichum musae* affected by different antagonistic concentration

Antagonist	Appressorium (%)		
	10^6	10^7	10^8
Bacterium			
TN-S221	1.7	0.0	0.0
TN-Y21	5.3	—[1]	90.9
TN-Y511	4.2	4.8	0.0
TP-Tu311	7.0	24.8	83.3
Yeast			
Y11-1	7.3	1.3	—
Y11-2	3.1	0.0	0.0
Y23-10	27.0	22.0	66.0
Y24-7	3.8	1.3	0.0
Y24-8	2.0	0.9	—
Control	0.0	0.0	0.0

[1] —: Not tested.

TABLE 6. Effect of antagonist concentration on control of banana anthracnose

Antagonist[1]	Lesion size (mm)				
	0	10^5	10^6	10^7	10^8
Bacterium					
TN-S221	14.4 a[2]	12.3 ab	11.3 ab	10.1 b	8.7 b
TN-Y21	15.1 a	13.8 ab	13.0 ab	12.4 b	12.3 b
TN-Y511	15.6 a	13.7 ab	12.2 bc	10.1 cd	8.5 d
TP-Tu311	15.3 a	13.9 ab	14.3 ab	13.3 ab	13.1 b
Yeast					
Y11-1	15.0 a	14.2 ab	13.9 ab	13.0 b	10.4 c
Y11-2	16.5 a	13.8 ab	11.9 b	12.0 b	10.7 b
Y23-10	15.6 a	13.7 bc	14.6 ab	12.7 cd	11.5 d
Y24-7	14.7 a	13.5 ab	11.9 bc	10.1 c	8.0 d
Y24-8	14.4 a	12.9 ab	10.7 bc	9.6 c	5.7 d

Concentration of anthracnose fungus was adjusted to 10^4/ml and 20 μl was added onto wound site of banana fruit after applying antagonists.
Means in each isolate followed by the same letter were not significantly different at $P = 0.05$ according to Duncan's multiple range test.

Effect of concentration of antagonists and pathogen on lesion development

Among 4 bacterial isolates and 5 yeast isolates tested, inhibitory effect to lesion expansion by the pathogen increased with increasing antagonist concentration when spore concentration of the pathogen was adjusted to 10^4/ml (Table 6). Lesion development was significantly reduced as antagonist concentration was higher than 10^7 cells/ml. Some isolates, such as TN-Y511, Y11-2, Y24-7, and Y24-8, were able to inhibit lesion expansion significantly at antagonist concentration of 10^6 cells/ml. All isolates, except Y23-10, at a concentration lower than 10^5 cells/ml did not significantly inhibit lesion development.

Preliminary test showed that antagonists were not able to reduce lesion size when the pathogen concentration was higher than 10^6 spores/ml. When cell concentration of the antagonist was fixed to 10^8/ml, antagonistic activity against pathogen decreased with increasing pathogen concentration (Table 7). All antagonists, except Tp-Tu311, showed inhibitory effect to lesion expansion when the pathogen concentration was lower than 10^4 spores/ml, compared to 10^6 spores/ml. Even pathogen concentration was as high as 10^5 spores/ml, some antagonists (TN-S221, Y23-10, Y24-7, and Y24-8) were still able to reduce lesion size.

Control of anthracnose disease

Numbers of lesion on ripe banana were reduced when green mature banana fruits were treated with antagonists before ripening (Table 8 &9). Effective of biocontrol on natural infection varied in different antagonists tested. Among 4 bacterial isolates tested, Tp-Tu311 was the most effective for control of the disease in Exp 2 (Table 8). For control of disease with antagonistic yeast, effective of biological control varied in different experiments (Table 9). It appeared that Y23-10 and Y24-8 were more effective to control the disease. In addition, 4 out of 5 antagonistic yeast were effective to control the disease under low inoculum potential in nature (Exp 3), however, antagonists were less effective to control the disease under high inoculum potential (Exp 1 & 2).

When the young banana fruits were sprayed with antagonistic bacteria (TN-Y21, Tp-Tu311) 48 hr after inoculation with the pathogen, lesions on harvested fruits were significantly reduced by the antagonists after ripening. Again, lesion development on harvested fruits treated with antagonistic bacteria same as used in the field was significantly reduced after ripening (Table 10).

DISCUSSION

Efficacy of different media for isolating bacteria and yeast from surface of green banana fruit greatly

TABLE 7. Antagonist on control of banana anthracnose affected by conidial concentration of *Collectotrichum musae*

Antagonist[1]	Lesion size (mm)			
	10^3	10^4	10^5	10^6
Bacterium				
TN-S221	6.5 c[2]	8.7 c	12.6 b	15.8 a
TN-Y21	11.1 c	14.3 b	15.7 ab	17.2 a
TN-Y511	7.4 b	9.9 b	13.6 a	15.8 a
TP-Tu311	12.4 b	15.9 a	17.5 a	18.3 a
Control	—[3]	19.8 a	20.0 a	20.3 a
Yeast				
Y11-1	8.7 c	12.1 b	15.4 a	17.3 a
Y11-2	9.3 c	12.3 bc	14.9 ab	17.3 a
Y23-10	7.6 d	10.7 c	12.9 b	15.9 a
Y24-7	7.5 d	9.9 c	12.5 b	15.2 a
Y24-8	4.7 c	9.1 b	11.1 b	15.0 a
Control	—	19.1 a	19.1 a	18.5 a

[1] Antagonist concentration was adjusted to 10^8/ml and 20 μl was added onto wound site of banana fruit before pathogen inoculation.
[2] Means in each isolate followed by the same letter were not significantly different at $P = 0.05$ according to Duncan's multiple range test.
[3] —: Not tested.

TABLE 8. Control of banana anthracnose from natural infection with antagonistic bacterium

Antagonist	Lesion number/finger	
	Exp 1	Exp 2
TN-S221	4.3	10.3 ab[1]
TN-Y21	8.2	12.3 ab
TN-Y511	4.5	10.6 ab
TP-Tu311	5.7	7.8 b
Control	10.2	16.6 a

[1] Seven banana fruits were used for each replication and four replications were done in the test. Means followed by the same letter were not significantly at $P = 0.05$ according to Duncan's multiple range test.

TABLE 9. Control of banana anthracnose from natural infection with antagonistic yeast

Antagonist	Lesion number/finger			
	Exp 1	Exp 2	Exp 3	Average
Y11-1	30.5 ab[1]	30.8 c	17.6 ab	26.3 ab
Y11-2	34.8 ab	54.5 a	9.9 bc	33.1 ab
Y23-10	34.5 ab	32.5 bc	6.3 c	24.4 b
Y24-7	36.8 ab	51.8 a	5.7 c	31.4 ab
Y24-8	25.3 b	42.3 abc	5.8 c	24.5 b
Control	47.8 a	46.5 ab	21.9 a	38.7 a

[1] Seven banana fruits were used for each replication and four replications were done in the test. Means followed by the same letter were not significantly at $P = 0.05$ according to Duncan's multiple range test.

TABLE 10. Control of banana anthracnose by antagonistic bacteria in field trial

Antagonist	Treatment[1]	Lesion number/finger	
		Exp 1	Exp 2
TN-Y21	A	46.0 a[2]	—[3]
TN-Y21	B	17.7 b	3.9 b
TP-Tu311	A	16.7 b	—
TP-Tu311	B	16.0 b	1.9 b
Control		64.8 a	21.9 a

[1] A : Antagonists were sprayed onto banana fruit 2 day after anthrancnose fungus inoculation in field.
B : Harvested fruits were immersed in antagonist suspension same as used in field for about 1–2 min before ripening.
[2] Means followed by the same letter in each column were not significantly at $P = 0.05$ according to Duncan's multiple range test. Banana was harvested on March 14, 1992 for Exp 1, and on May 25, 1992 for Exp 2.
[3] — : Not tested.

varied, indicating that nutrient requirement for different microorganisms might vary. Thus isolation efficiency might be significantly different under various nutrient conditions. Present results showed that isolation of bacteria and yeast was more effective by NYDA than by BPEA and APDA. Not only higher population density but also more diversities of microorganisms were obtained from surface of green banana by using NYDA, partly because NYDA might contain more complex and rich nutrient.

Although microbial populations might greatly vary on the surface of green banana obtained from various sources, population of microorganisms in the peel extracts of green banana incubated in enrichment media for 3 days might reach a constant that was independent to the initial amount of microorganisms added. It suggests that microbial population is controlled by the carrying capacity of the substrate (5). In addition, microflora became simple at the equilibrium; diversity of microflora decreased. Only few kinds of dominant microorganisms appeared in the enrichment media might result in nutrient competition among microorganisms (1). This phenomenon is similar to the succession of microorganisms on leaf surface (7,28).

Compared colony types of microorganisms obtained from the surface of green banana, results showed that microflora was quite similar and simple on the surface of fruits collected from different banana plantations. It suggests that exudates of green banana from different locations might be the same. Under this condition, it might select for microorganisms that have similar ability to utilize the nutrient and to colonize the fruit surface. If this is the case, then success of biological control by manipulating nutrient requirement

to enhance growth and multiplication of antagonists on the fruit surface will greatly increase. Janisiewicz et al (15) reported that nutrient could be used to enhance the population of the antagonists and the resulting biocontrol of blue mold on ripe apple.

In many cases, biological control of diseases can be achieved in green house tested, but the efficacy of biological control is inconsistent in field trials (6,28). Suppressing antagonistic activity of biocontrol agents in fields by the other microorganisms might partly account for these results. In the present study, we screened antagonists by using two-step method to improve this deficiency; effective combinations of microorganisms were selected in the first step, and each isolate in the effective combination was tested in the second step. Since each isolate of antagonists obtained from effective combination of 10 isolates might have good competitive ability in preliminary test, otherwise, the mix of 10 isolates might not be effective to control the disease. Consistency of the effective control of biocontrol agents obtained from this method might increase in nature. Therefore, antagonists used in this experiment were consistently effective to control the disease in artificial inoculation test and in natural infection.

Usually, increased efficiency of biological control was associated with increased antagonist populations and decreasing challenge spore levels. This phenomenon was also found in our results. McLaughlin *et al.* (16) reported that the effective concentrations of antagonistic yeast to control Botrytis rot and Penicillium rot of apple were different. Our findings showed that efficacy of biological control of banana anthracnose might greatly vary with antagonists tested. Similar results have also been observed in other investigations (17). All these results suggest that interaction between different antagonist and pathogen might produce various degrees of disease control.

Among 9 antagonists tested, all of them were not able to inhibit spore germination of the pathogen on water agar. However, 6 isolates were able to inhibit appressorium formation from germinating spore. Although the reminders at high cell concentration enhanced appressorium formation, the appressoria became hyaline and swell which might loss normal function as latent structure. In addition, efficiency of biological control by these antagonists in artificial infection assays was not paralleled to that in natural infection. These suggest that mechanisms of biological control by these antagonists might be different.

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摘　　要

莊再揚[1]、楊宏仁[2]. 1993. 香蕉炭疽病之生物防治. 植病會刊2:71-77. (1. 台北市　國立台灣大學植物病蟲害學系，2. 台中縣　台灣省農業試驗所)

利用NYDA、APDA及BPEA等培養基由青香蕉果皮上分離細菌與酵母菌，無論在微生物種類與數量上，均以NYDA的分離效果最好。若將果皮淋洗液在25 C培養於增量培養基3天後，細菌量增加10^5-10^8倍，而酵母菌增加10^5-10^6倍，但菌落形態種類卻減少。由台灣西部蕉園青香蕉果皮所分離的412株細菌與217株酵母菌，經接種試驗，祇有4株細菌與5株酵母菌能有效抑制炭疽病斑的擴展，抑制率分別爲22%-43%以及32%-43%。抑制效果隨著拮抗菌濃度增加而增加，但隨著病原菌濃度增加而降低。而拮抗菌細胞濃度即使高達10^8/ml，亦無法抑制病原菌胞子發芽。在自然感染蕉果的防治試驗中，祇有1株細菌和2株酵母菌能有效抑制炭疽病斑的出現。

關鍵詞：香蕉炭疽病、生物防治、*Colletotrichum musae*。