Management of the Sigatoka disease complex in banana plant under two cultivation systems

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Abstract – The production of organic food has been increasing in recent years. However, there is lack of information to guide organic banana producers in Santa Catarina state. Among the demands is the control of Sigatoka disease complex (which comprises black and yellow Sigatokas). The management of this disease complex involves a combination of control measures to keep the severity of the disease at low levels. Thus, the objective of this work was to evaluate the severity of the Sigatoka disease complex across six banana genotypes grown under two production systems. For that, banana genotypes were planted in two areas. In one area, chemical fertilizer and fungicides were applied, and in the other area, bioinputs and fertilizers that can be used in organic production were employed. The severity of the Sigatoka disease complex was evaluated every 20 days for three production cycles. The experiment was designed in randomized blocks in a 2 (systems of cultivation) × 6 factorial (cultivars) scheme with three replications. Tetraploid banana hybrids showed lower disease severity. On the other hand, the cultivars SCS452 Corupá and SCS454 Carvoeira were the most susceptible ones. Plants that received anaerobic fertilizer and organic fertilizers showed similar severity of Sigatoka compared to plants that received fungicides and chemical fertilizers.

Keywords: *Musa* spp.; bioinputs; *Pseudocercospora fijiensis; Pseudocercospora musae.*

Manejo do complexo de sigatoka em bananeiras cultivadas sob dois sistemas de cultivo

Resumo – A produção de alimentos orgânicos tem aumentado nos últimos anos. Entretanto, existe uma escassez de informações para orientar os produtores catarinenses de banana orgânica. Entre as demandas está o controle do complexo de sigatoka (que inclui as sigatokas amarela e negra). O manejo deste complexo de doenças envolve a combinação de medidas de controle para que a severidade da doença permaneça em níveis baixos. Assim, o objetivo deste trabalho foi avaliar a severidade do complexo de sigatoka em seis genótipos de bananeiras cultivados sob dois sistemas de cultivo. Para isso, os genótipos de bananeiras foram plantados em duas áreas. Em uma área foi aplicado adubo químico e fungicidas, e na outra área foram fornecidos bioinsumos e adubos permitidos na produção orgânica. A severidade do complexo de sigatoka foi avaliada a cada 20 dias por três ciclos de produção. O experimento foi conduzido em blocos casualizados em esquema fatorial 2 (sistemas de cultivo) x 6 (cultivares), com três repetições. Os híbridos tetraploides de bananeira apresentaram menor severidade da doença. Já os cultivares SCS452 Corupá e SCS454 Carvoeira foram os mais suscetíveis. Plantas que receberam o biofertilizante anaeróbico e adubação orgânica apresentaram severidade da sigatoka semelhante às plantas que receberam os fungicidas e adubos químicos.

Palavras-chave: *Musa* spp.; bioinsumos; *Pseudocercospora fijiensis; Pseudocercospora musae.*

Introduction

Brazil is one of the world's largest banana producers (FAOSTAT, 2025). Santa Catarina is the fourth largest producing state, with around 3,800 producers who produce about 678 thousand tons of fruit (Epagri/Cepa, 2024).

In turn, organic production has increased in recent years. According to Lima *et al.* (2020), the cultivated area destined for organic crops in the world increased almost 10% per year from 2000 to 2017. In Brazil, the growth rate of the area planted with organic crops was 2% per year from 2007 to 2017. Based on the database of the Brazilian National Registry of Organic Producers (CNPO), updated in January 2025, there are more than 25,000 organic producers in Brazil, of which 8,269 produce bananas. In Santa Catarina, there are 1,396 organic producers and 574 organic banana producers (Mapa, 2025).

Several diseases can cause damage to banana plants, with the Sigatoka disease complex occupying a major position. This complex of diseases includes black and yellow Sigatokas, caused by two species of *Pseudocercospora*: *P. fijiensis* and *P. musae*, respectively (Guimarães *et al.*, 2023). These pathogens cause necrosis in the leaves, which reduces the production and quality of the fruits (Nomura *et al.*, 2015), especially in situations of absent or deficient control, such as the organic production system (Beltrame; Scherer, 2023 Peruch; Sônego, 2007). To manage these diseases, it is recommended to

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use several control measures, such as removal of necrotic leaf, balanced fertilization based on soil analyses, planting resistant cultivars, and spraying of fungicides (Guimarães *et al.*, 2023).

However, few alternative products can be applied to control the Sigatoka disease complex in banana plantations grown under organic systems. Thus, the management of these diseases is one of the great challenges faced by organic banana producers.

Therefore, this study aimed to evaluate the severity of the Sigatoka disease complex in six banana genotypes, grown under two cultivation systems (conventional and organic).

Material and methods

The experiment was conducted at the Estação Experimental of Epagri in Itajaí-SC (Brazil), which has a humid subtropical climate (Cfa in the Köppen classification), with an average temperature of 20.2°C and an average annual precipitation of 1,596mm.

Banana plants of the genotypes BRS SCS Belluna; Tetraploid hybrids BRS Princesa and BRS Platina; Bagban 191 (mutation of the Figo subgroup, with shorter pseudostem height); SCS452 Corupá (Cavendish subgroup); and SCS454 Carvoeira (Prata subgroup) were planted in two areas 600 m apart. In each area, every genotype was planted in three plots composed of 16 plants, and the central plants of each plot were evaluated. The experimental design was conducted in randomized blocks, in a 2 (crop systems) × 6 (cultivars) factorial scheme. Before transplanting the seedlings, soil acidity was corrected with limestone, according to the soil analysis of each area. Likewise, fertilizer doses were recommended according to the soil analysis and production estimate of 40t ha^{-1} cycle^{-1} (CQFS RS/SC, 2016). Banana plantation management was carried out following technical recommendations for the state of Santa Catarina (Guimarães *et al.*, 2023). In one of the areas, bioinputs and fertilizers certified for organic production were used; in the other area, conventional fungicides and fertilizers. Throughout this work, the areas will be called organic and conventional, respectively.

In the organic area, the plants were fertilized with a mixture of composted swine waste (N = 2.5%; P_2O_5 = 2.0%; K_2O = 0.8%), cattle hoof and horn meal (N = 15%), and potassium sulfate of mineral origin (K_2O = 50%). The banana plants in the conventional area were fertilized with ammonium sulfate (N = 21%), triple superphosphate (P_2O_5 = 40%), and potassium chloride (K_2O = 60%). The fertilizer doses were divided into five applications during the growth period of the plants, being applied in a half-moon pattern in front of the daughter plant.

The management of the spontaneous plants was carried out by means of mowing grass trimming machine. In addition, during the month of May of each cycle, a seed mixture composed of *Raphanus sativus* (2.5%), *Brassica rapa* (3.5%), *Secale cereale* (26%), *Avena sativa* (28%), and *Avena strigosa* (40%) was sown in the organic area.

For Sigatoka disease complex management, genotypes with different levels of resistance were evaluated, periodic leaves removal were performed, and different products were applied. The products used in the organic area included *Melaleuca alternifolia* oil interspersed with *Bacillus subtilis* (first evaluation cycle), anaerobic biofertilizer (second evaluation cycle), and citrus biomass (third evaluation cycle). In turn, in the conventional area, fungicides were sprayed alternating different modes of action. The active ingredients used were: propiconazole (triazole); pyrimethanil (anilinopyrimidine); difenoconazole (triazole); azoxystrobin + difenoconazole (strobilurin + triazole); and pyraclostrobin + epoxiconazole (strobilurin + triazole).

In both areas, commercial products were sprayed following the manufacturers' recommendations for banana crops.

To prepare 100L of biofertilizer, the following were used: microorganism source: 12.5kg of fresh cow manure; mineral sources: 10kg of sieved rock dust, 7.5kg of natural phosphate, 5kg of potassium sulfate, 2.5kg of sieved ash, 0.5kg of boric acid, and 0.5kg of zinc sulfate; energy sources: 25L of sugarcane juice or 5kg of brown sugar, 5L of milk, and 10kg of mashed ripe banana. A plastic drum-type container with a volume of 200 liters was used for the fermentation process. All the water and manure were added to half the container's capacity, along with 10% of the mineral source and 25% of the energy source. Every two days, 8.4% of the energy source and 10% of the mineral source were added until they were completely used. In addition, the product was mixed daily to submerge the layer of solids that floated on the surface (called the "cap"), until the fermentation process was complete, when the solid layer no longer floated. This process took about 30 days. After this period, the biofertilizer was leached and stored without exposure to direct sunlight up to 12 months. The spray mixture was composed of 4L ha^{-1} of mineral oil and 8L ha^{-1} of biofertilizer.

The applications of the products to control diseases were conducted with a banana spray can, using a spray volume of 40L ha^{-1} every 30 days.

Sigatoka severity was assessed every 20 days, following the scale proposed by Gauhl (1994), in which: 0 = absence of symptoms; 1 = up to 1%; 2 = 1% to 5%; 3 = 6% to 15%; 4 = 16% to 33%; 5 = 34% to 50%; and 6 = 51% to 100% of the leaf blade with symptoms.

The infection index (II) was estimated using the following formula:

$$II(\%) = \frac{\sum nb}{[N-1]xT} x\,100$$

In which: n = number of leaves in each degree of the scale; b = degree of the scale; N = number of degrees of the scale; and T = total number of leaves on each plant. The II was used to estimate the area under the disease progress curve (AUDPC), using the equation proposed by Campbell and Madden (1990):

$$AUDPC \sum \frac{y_1 + y_{i+1}}{2} x\left(t_{i+1} - t_i\right)$$

In which: yi is the II of the plant at time ti, and yi+1 is the IF of the plant at time ti+1.

The data were subjected to the Shapiro-Wilk normality test and the Bartlett homogeneity of variances test. Then, an analysis of variance (ANOVA) was performed. The means were compared by the Scott-Knott test, at a 5% significance level. In addition, the least squares means (LSMeans) with a

95% confidence interval were estimated and compared by the Student's t-test at 1%. The analyses were performed in the R software (R Core Team, 2024), with the aid of the AgroR and means packages.

Results and discussion

The cultivars BRS Princesa and BRS Platina showed lower sigatoka severity than the other cultivars in all three production cycles, regardless of the cultivation method (Figures 1A, 2A and 3A).

In the first evaluation cycle, in which *M. alternifolia* oil witherspersed *B. subtilis* were sprayed, the genotypes BagBan 191, SCS452 Corupá and SCS454 Carvoeira showed the highest AUDPC of the disease ($p = 2e^{-16}$). However, the AUDPC of the Sigatoka disease complex in each cultivar did not vary according to the cultivation method (Figure 1A).

On the other hand, plants grown in the organic area showed greater severity of the Sigatoka disease complex than those grown in the conventional area (Figure 1B).

In the second evaluation cycle, in which anaerobic biofertilizer was applied, 'SCS452 Corupá' and 'SCS454 Carvoeira' showed the highest AUDPC of the disease complex ($p = 2{,}83e^{-12}$). However, no significant differences were observed within the cultivars about the cultivation systems (Figure 2A).

Similarly, in the second evaluation cycle, there were no significant differences in the severity of the Sigatoka disease complex when comparing the organic and conventional areas (Figure 2B).

In the third evaluation cycle, in which citrus biomass was sprayed, the cultivars BRS SCS Belluna, SCS452 Corupá, and SCS454 Carvoeira showed greater disease severities in the organic area compared to the conventional area (Figure 3A). The cultivars 'SCS452 Corupá' and 'SCS454 Carvoeira' also presented higher AUDPC in this cycle ($p = 5{,}11e^{-14}$).

When comparing the two areas, in the third evaluation cycle, the organic one showed greater severity of the Sigatoka disease complex compared to the conventional area (Figure 3B).

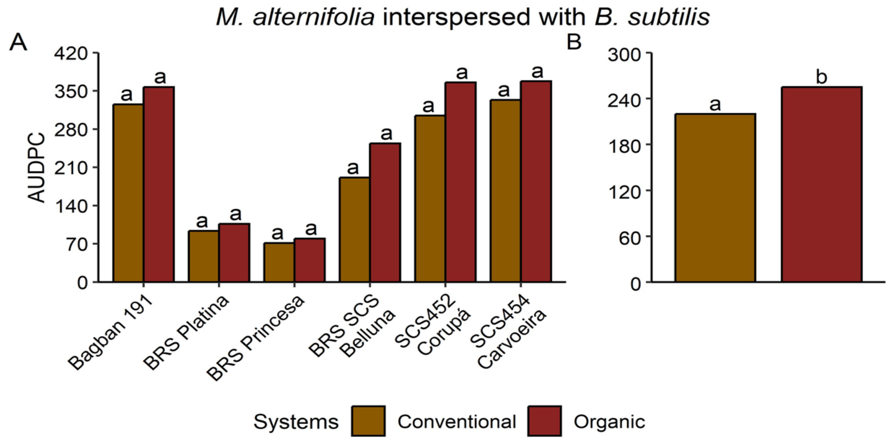

Figure 1. Area under the disease progress curve (AACPD) of Sigatoka disease complex evaluated in different banana genotypes. (A) AACPD of genotypes cultivated under two cultivation strategies; (B) AACPD of two cultivation systems. Means within each cultivar (A) or of cultivation systems (B) followed by the same letter do not differ significantly by the Scott-Knott test ($p < 0.05$)
Source: Elaborated by the Authors (2025)
Figura 1. Área abaixo da curva do progresso da doença (AACPD) do complexo de sigatoka avaliada em diferentes genótipos de banana. (A) AACPD dos genótipos cultivados sob duas estratégias de cultivo; (B) AACPD nos dois sistemas cultivo. Médias dentro de cada cultivar (A) ou dos sistemas de cultivo (B) seguidas de mesma letra não diferem significativamente pelo teste de Scott-Knott (p < 0,05)
Fonte: Elaborado pelos autores (2025)

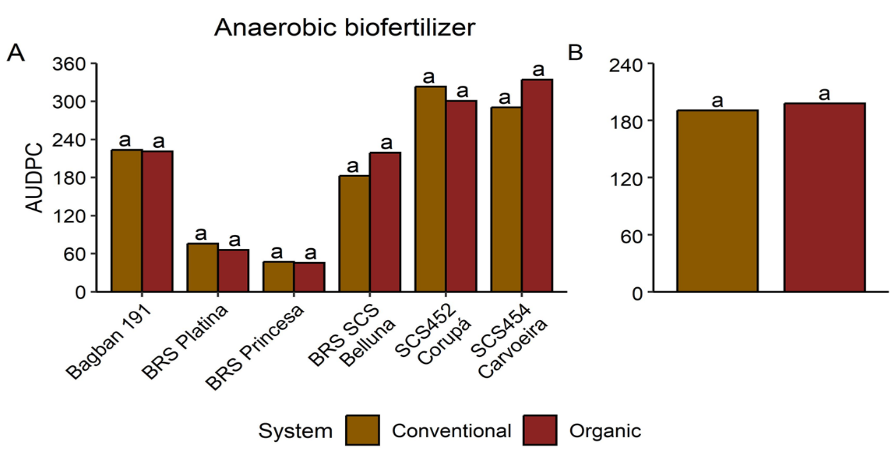

Figure 2. Area under the disease progress curve (AACPD) of Sigatoka disease complex evaluated in different banana genotypes. (A) AACPD of genotypes cultivated under two cultivation strategies; (B) AACPD of two cultivation systems. Means within each cultivar (A) or of cultivation systems (B) followed by the same letter do not differ significantly by the Scott-Knott test ($p < 0.05$)
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Fonte: Elaborado pelos autores (2025)

Finally, joint analyses of the data showed that, regardless of management, the cultivars BRS Platina and BRS Princesa presented the lowest AUDPC ($p < 0.0001$). However, 'SCS452 Corupá' and 'SCS454 Carvoeira' had higher AUDPC compared to 'BRS SCS Belluna' and BagBan191 ($p < 0.0001$). In addition, no interaction was observed between genotype and production system ($p = 0.178$) (Figure 4A).

When estimating the AUDPC according to the products evaluated, it was observed that the lowest values were obtained in the treatments with fungicide and anaerobic biofertilizer (Figure 4B). Citrus biomass and alternating spraying of *M. alternifolia* with *B. subtilis* oil showed AUDPC 10% and 23% higher, respectively, when compared to fungicide treatment. Finally, AUDPC in the organic area was approximately 15% higher than in the conventional area (Figure 4C).

The results of this study indicate different reactions of the genotypes to the Sigatoka disease complex (Figure 4A). Tetraploid hybrids showed greater resistance to the disease. The highest AUDPC were observed in the cultivars SCS452 Corupá and SCS454 Carvoeira. Similar results were found in other studies (Beltrame; Scherer; Haro, 2023; Dianese *et al.*, 2020; Gonçalves *et al.*, 2021). The reaction of the BagBan 191 genotype to the sigatoka disease complex was unknown, but the results obtained indicate that this genotype has moderate resistance to the Sigatoka disease complex.

Planting resistant banana trees is a strategy for managing these diseases. However, it is important to note that certain varieties may have limitations, such as lower consumer acceptance when compared to the Pomme and Cavendish subgroups (Guimarães *et al.*, 2023; Oliveira *et al.*, 2013).

With regard to bioinputs, it was found that the control efficiency of the Sigatoka disease complex varied depending on the product used. Anaerobic biofertilizer was the only product that showed control efficiency similar to fungicides. Several studies have shown that citrus biomass, *M. alternifolia*, and *B. subtilis* controlled sigatoka in banana trees (Gutierrez-Monsalve *et al.*, 2015; Peruch *et al.*, 2015, Reuveni; Arroyo; Ovadia, 2020). However, there is a lack of studies showing the efficiency of the anaerobic biofertilizer evaluated in the control of the Sigatoka disease complex. The results obtained in this study suggest that the anaerobic biofertilizer may be another option for the control of these diseases.

Conclusion

-The tetraploid hybrids BRS Platina and BRS Princesa showed lower

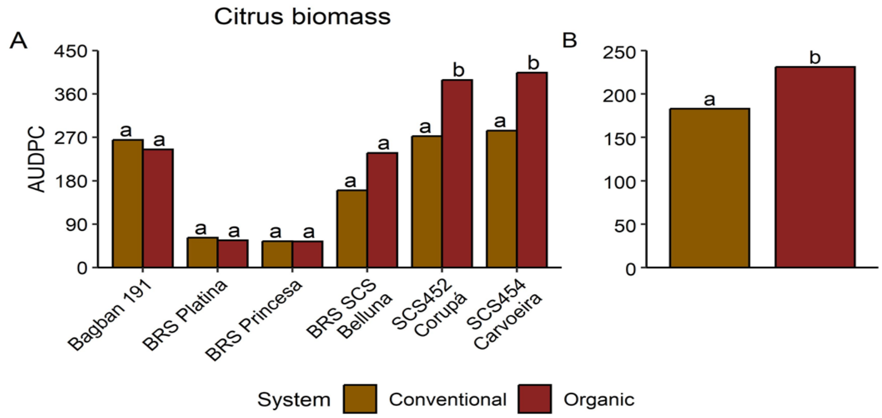

Figure 3. Area under the disease progress curve (AACPD) of Sigatoka disease complex evaluated in different banana genotypes. (A) AACPD of genotypes cultivated under two cultivation strategies; (B) AACPD of two cultivation systems. Means within each cultivar (A) or of cultivation systems (B) followed by the same letter do not differ significantly by the Scott-Knott test ($p < 0.05$)

Source: Elaborated by the Authors (2025)

Figura 3. Área abaixo da curva do progresso da doença (AACPD) do complexo de sigatoka em diferentes genótipos de banana. (A) AACPD dos genótipos cultivados sob duas estratégias de cultivo; (B) AACPD nos dois sistemas cultivo. Médias dentro de cada cultivares (A) ou dos sistemas de cultivo (B) seguidas de mesma letra não diferem significativamente pelo teste de Scott-Knott (p < 0,05)

Fonte: Elaborado pelos autores (2025)

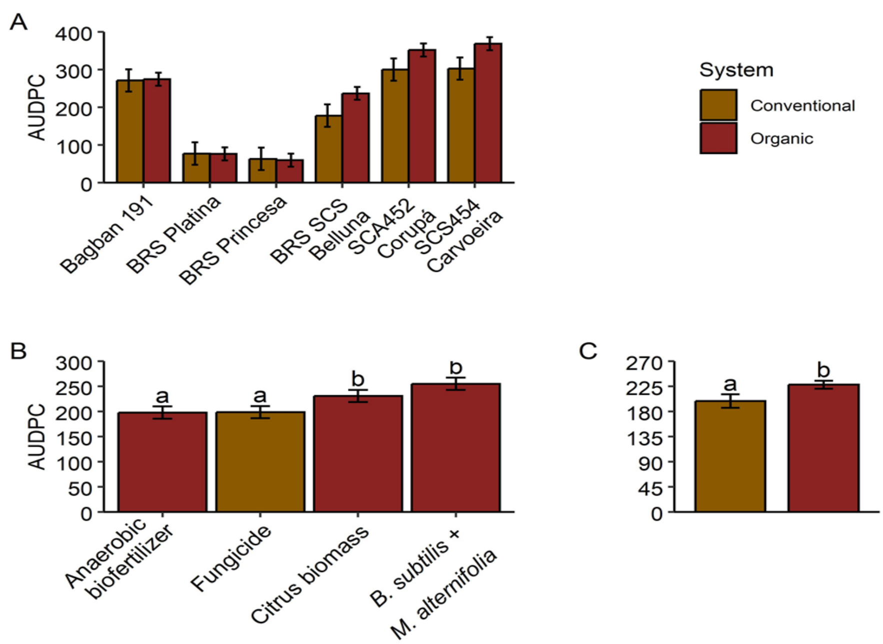

Figure 4. Area under the disease progress curves (AACPD) of Sigatoka disease complex evaluated in different banana genotypes. (A) AACPD of genotypes cultivated under two cultivation strategies; (B) AACPD of two cultivation systems. (C) AACPD of bioinputs and fungicides. Bars represent least squares means and 95% confidence intervals. Means followed by the same letter do not differ significantly by the t-test ($p < 0.01$)

Source: Elaborated by the Authors (2025)

Figura 4. Área abaixo da curva do progresso da doença (AACPD) do complexo de sigatoka avaliada em diferentes genótipos de banana. (A) AACPD dos genótipos cultivados sob duas estratégias de cultivo; (B) AACPD nos dois sistemas cultivo. (C) AACPD dos bioinsumos e fungicidas. Barras representam médias dos mínimos quadrados e intervalo de confiança de 95%. Médias seguidas de mesma letra não diferem significativamente pelo teste-t (p < 0,01)

Fonte: Elaborado pelos autores (2025)

severities of the Sigatoka disease complex;

-The severity of the Sigatoka disease complex in banana plants that received spraying of anaerobic biofertilizer and fertilizers used in organic farming was similar to that of plants that received spraying of fungicides and chemical fertilizers.

Author contributions

André Boldrin Beltrame: Conceptualization, Data curation, Investigation, Formal analysis, Methodology, Validation, Data visualization (infographic, flowchart, table, graph), Writing – first draft, Writing – review & editing. **Gelton Geraldo Fernandes Guimarães:** Conceptualization, Investigation, Methodology, Project administration, Resources, Data visualization (infographic, flowchart, table, graph), Writing – first draft. **Ricardo José Zimmermann Negreiros:** Conceptualization, Methodology, Writing – first draft, Writing – review & editing. **Ramon Felipe Scherer:** Conceptualization, Investigation, Methodology, Writing – first draft. **Vitor Paulo Kieckhoefel Santos:** Investigation. **Márcio Sônego:** Conceptualization, Resources, Writing – first draft. **Mauro Ferreira Bonfim** Junior: Conceptualization, Writing – first draft.

Conflict of interest

The authors declare no conflict of interest in this work.

Research data

Data will be made available by the author upon request.

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