Biocontrol of Potato Common Scab Cultivated on Different Soil Mulch

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1. Introduction

Potato common scab, caused by the bacterial species of the genus Streptomyces, is a plant disease of worldwide importance. Streptomyces spp. cause scab damage in tubers by forming necrotic, superficial, raised, or deep-pitted lesions on their surface during development, rendering them unsuitable for the market, and causing significant economic losses in potato farming [1].

In Brazil, the species associated with potato common scab are Streptomyces scabiei, Streptomyces croiscabies, Streptomyces setonii, Streptomyces sampsonii, and the recently identified Streptomyces brasiliscabiei that is prevalent in Southern Brazil, causing 30–90% losses in tubers of marketable size according to producers [2].

The use of susceptible potato varieties and contaminated seed potatoes, continuous planting on infested soils, soil compaction, and changes in soil microbiota arising from the indiscriminate use of pesticides promote the incidence of the common scab [3].
Chemical control using Fluazinam® and crop management strategies have proved inefficient in controlling this disease. Thus, biological control agents have been studied and used as alternative or complementary tools for other phytosanitary control strategies [1].

The use of biological control agents reduces the inoculum or biological activity of phytopathogenic organisms by introducing a competitor or inhibitor [4]. Phytosanitary biocontrol presents certain important advantages in agricultural production, including the reduced use of chemical as well as residual pesticides in food production, increased production area sustainability via increased microbial population, reduced production costs, and plant growth promotion, thus sustainably and satisfactorily contributing to increased agricultural production yields [5].

Trichoderma spp. and Bacillus subtilis are the most frequently employed fungi and bacterium biocontrol agents, respectively, because of their high adaptability and sustainability in soil under diverse environmental conditions. Moreover, the possession of several biocontrol mechanisms enables them to overcome phytopathogenic defenses [6].

The efficiency of Trichoderma spp. and B. subtilis in controlling phytopathogenic fungi has been reported in the literature [4,7–9]. However, reports on Trichoderma spp. for the control of bacterial strains are scarce [9–11].

Recently, a Trichoderma sp. and B. subtilis-based commercial product has been reported to reduce the incidence of potato common scab, consequently increasing marketable tuber production [12] and providing evidence for the effectiveness of biological agents in controlling scab-induced damage. However, the individual contribution of the agents (Trichoderma sp. and B. subtilis) to the control of the common scab and its impact on production were not discussed.

In addition to biocontrol, the introduction of organic matter into the soil can provide greater effectiveness to the action of antagonistic microorganisms in the soil, helping to maintain the microbial colonies in the environment by controlling phytopathogen population levels [13]. The severity of potato common scab has been reported to reduce after the introduction of green manure and crop rotation, which increased the rhizosphere microflora, an antagonist of soil phytopathogens [14].

Vetch (Vicia sativa), from the Fabaceae family, has a high protein content due to its high N-fixing capacity, and is therefore a forage legume and green fertilizer. In sustainable agriculture, vetch has a function beyond plant nutrition, and has also been used to favor the maintenance of soil microbiota, increasing population and enzymatic activity [15]. In Brazil, as most crop succession plants used as forage are grass, it is worth studying the performance of vetch in controlling potato scab and increasing tuber production.

Therefore, it is important to examine the effects of biological control in conjunction with soil organic matter, as well as their interactions, on plant disease control to design and optimize strategies that maximize the productive potential of the plants and maintain the effective functioning of soil microbiomes for promoting a viable production system.

In this study, we tested the effects of two Trichoderma spp. as biocontrol agents on potato common scab. In addition, we tested the effect of Trichoderma spp. and B. subtilis in combination with cover crop matter from vetch or palisade grass to evaluate the action of mulch and biological agents in the control of Streptomyces sp., the causal agent of potato common scab. This study allowed us to verify the contribution of each biocontrol agent and organic matter content to disease control, in addition to the interaction between the biological agents and cover crops on the scab-caused damage and their impact on commercial production.

2. Materials and Methods

The influence of the biological control agents on potato common scab was evaluated by performing two experiments at different sites, located in two separate areas, in the state of Bahia, Brazil, which has a recent history of potato common scab incidence. A previous survey indicated that S. scabiei was the recurrent species in the study region [16], with greater prevalence in soils of pH above 5.2 [17].
2.1. Assay with Trichoderma spp. (Test 1)

The first experiment was conducted at 13°02′04.52″ S latitude and 41°27′36.09″ W longitude, with a previous history of 53% production loss caused by the potato common scab. In this assay, seed tubers of Agata cultivar types I, II, and III of different generations were planted and subjected to the following treatments: Trichoderma longibrachiatum (TL) strain FL1 (2 × 10^8 CFU g^-1) from TrichonemateMax® (commercial product), Trichoderma asperellum (TA) strain FA1 (2 × 10^8 CFU g^-1) from TrichobiolMax® (commercial product), and control treatment (without microorganisms). The registration process is ongoing for the commercial use of both of these microorganisms in Brazil.

The experiment was conducted in a strip design with 10 repetitions in an area containing organic residual palisade grass (Brachiaria brizantha), which was cultivated prior to potato planting. The grass was incorporated into the soil that had been previously fertilized with 360 kg ha^-1 of P_{2}O_{5}, and type III seed potato tubers of generation 2 Agata were planted by applying each treatment to one quadrant of the study area under a 100 ha central pivot irrigation system to reduce cross-contamination risk between treatments.

After sowing, the microorganisms were applied at a dosage of 10 kg ha^-1 using inoculated substrate (mixed with 3000 L of water and applied via irrigation), repeated every 15 days. The field was irrigated in a central pivot, and any other handling followed the prescribed recommendations for potato crops. At 89 days after planting (DAP), the aerial part of the plants was desiccated to complete the tuber filling and maturation. After 10 days, 18 sufficiently distributed points were sampled in each quadrant of the pivot area, with plots of two 5 m lines.

2.2. Assay with Organic Matter and Biocontrol Agents (Test 2)

The second experiment was performed in a field at 13°15′42.95″ S latitude and 41°32′56.51″ W longitude, using a randomized block design in an area designated for commercial potato production. A lane experiment scheme (two types of mulch) and biocontrol agents (four treatments) were employed with three replicates each in plots containing eight 5 m planting lines.

The study area had a history of 89% scab-induced production loss in the year prior to the experiment. The area was sown and covered with palisade grass (B. brizantha), which is the standard procedure used by the regional producers after a new harvest to cover the soil until the next crop sowing. After one year, a strip of the contaminated area was opened, and palisade grass cover was incorporated into the soil. In the opened strip, common vetch was sown, cultivated for three months, and the plant material was incorporated into the soil; palisade, growing in another area adjacent to the vetch-cultivated one, was also incorporated into the soil. Both types of covers, in addition to antagonistic microorganisms, were used to test the control of potato common scab.

Both types of covered strips were treated with: TL strain FL1 (2 × 10^8 CFU g^-1) from TrichonemateMax® (commercial product); TA strain FA1 (2 × 10^8 CFU g^-1) from TrichobiolMax® (commercial product); B. subtilis + B. licheniformis + T. longibrachiatum (BSBLTL; 3.75 × 10^9 CFU g^-1) from Nem Out®, a commercial formulation wettable powder; B. subtilis + Enterococcus faecium + Lactobacillus plantarum (BSEFLP; 3 × 10^9 CFU g^-1) from Compost Aid®, a commercial formulation wettable powder; and the control (no microorganism).

The soil was fertilized with 360 kg ha^-1 of P_{2}O_{5} prior to planting, and type III, generation 2 seed tubers of Ágata were planted in rows along the strips. Thereafter, three 5 m linear plots with six planting lines were established. After sowing, microorganisms were first applied at a dosage of 15 kg ha^-1 via irrigation and repeated every 15 days. Irrigation was performed in a center pivot, and any other handling followed the prescribed recommendations for potato crop. At 78 DAP, the aerial part of the plants was desiccated to complete the tuber filling and maturation.
2.3. Production Survey and Soil Collection

Ten days after applying the desiccant to each experiment, tubers were collected from each sampling point in the experiment plot 1 or 2, separated, classified as marketable or non-marketable (commercial without scab defects and non-commercial with scab damage), and weighed to evaluate the production. Other damage to the tubers represented approximately 1% of the total production; therefore, they were rejected for the analysis. In addition, soil samples were collected from each sampling point for chemical analysis (Table 1).

<table>
<thead>
<tr>
<th>Assay</th>
<th>Treatments</th>
<th>OM (dag mg⁻³)</th>
<th>pH</th>
<th>K (mg dm⁻³)</th>
<th>P¹</th>
<th>H + Al</th>
<th>Ca (cmolc dm⁻³)</th>
<th>Mg</th>
<th>BS (%)</th>
<th>CEC</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T</td>
<td>2.27</td>
<td>5.5</td>
<td>142.00</td>
<td>152.53</td>
<td>5.64</td>
<td>2.53</td>
<td>0.81</td>
<td>3.62</td>
<td>9.26</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>TL</td>
<td>2.23</td>
<td>5.5</td>
<td>150.02</td>
<td>164.52</td>
<td>5.73</td>
<td>2.92</td>
<td>0.73</td>
<td>3.99</td>
<td>9.67</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>TA</td>
<td>2.35</td>
<td>5.4</td>
<td>142.35</td>
<td>149.74</td>
<td>6.21</td>
<td>2.62</td>
<td>0.82</td>
<td>3.78</td>
<td>9.95</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>BA</td>
<td>1.70</td>
<td>6.2</td>
<td>196.21</td>
<td>170.14</td>
<td>2.62</td>
<td>3.61</td>
<td>0.92</td>
<td>4.91</td>
<td>7.50</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Grass</td>
<td>1.72</td>
<td>6.2</td>
<td>198.15</td>
<td>178.16</td>
<td>2.61</td>
<td>3.53</td>
<td>0.94</td>
<td>4.91</td>
<td>7.51</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Vetch</td>
<td>1.71</td>
<td>5.3</td>
<td>210.33</td>
<td>188.02</td>
<td>4.33</td>
<td>2.02</td>
<td>0.61</td>
<td>3.14</td>
<td>7.44</td>
<td>42</td>
</tr>
</tbody>
</table>

¹ Melich; TA = T. asperellum; TL = T. longibrachiatum; T = control.

2.4. Severity of Illness and Losses

After classifying and weighing the tubers, parameters including marketable tuber weight, scab-injured tuber weight, number of injured tubers, and lesion area using the diagrammatic lesion scale [18] were measured; severity [19] was calculated using Equation (1):

\[ Sev = \left( \frac{(N1 \times F1) + (N2 \times F2) + (N3 \times F3) \ldots}{N1 + N2 + N3 \ldots} \right) \times 20, \]  

where \( N \) is the note diagrammatic scale and \( F \) is the frequency or number of lesion-infested tubers. Percentage losses, obtained by comparing the total injured tuber weight with total weight, were also analyzed.

2.5. Statistical Analysis

Data pertaining to the production survey and the severity of illness and loss were collected and statistically analyzed using analysis of variance with an F-test \((p < 0.05)\); the experimental mean values were compared using Tukey’s test \((p < 0.05)\) by employing the AgroEstat© software. A multivariate analysis was performed on the parameters of production and plant disease using principal component analysis, in which their correlations were examined to understand the responses.

3. Results

3.1. Severity and Yield Post Application of Trichoderma spp.

Biocontrol results of the common potato scab in the Trichoderma spp. experiment are shown in Figures 1 and 2. TL treatment significantly influenced the incidence of injured tubers compared with the control (Figure 1a). Tubers treated with TL showed a 90.2% decrease in lesions, whereas those with TA showed only 25.7%.

Compared with the control, TL reduced the size of the lesions by 66.64% (Figure 1b), whereas TA achieved only a 33.93% reduction, which was non-significant compared with the control.

A similar result was observed for disease severity (Figure 1c), with a 56.75% reduction in TL-treated plants compared with that in the control. In contrast, TA treatment exhibited a non-significant reduction in disease severity (34.75%).
A similar result was observed for disease severity (Figure 1c), with a 56.75% reduction in TL-treated plants compared with that in the control. In contrast, TA treatment exhibited a non-significant reduction in disease severity (34.75%). TL reduced the production losses caused by the common scab (Figure 1d) by 89.78% compared with that in the control. In contrast, TA reduced the production loss by 15.96%.

Figure 1. (a) Injured tuber incidence, (b) potato common scab-injured superficial area, (c) disease severity index, and (d) production loss (%) as a function of biocontrol agents. TA = *T. asperellum*, TL = *T. longibrachiatum*, T = control. Mean values followed by the same alphabets did not differ significantly based on Tukey’s test \((p < 0.05)\); CV (%): (a) 21.4, (b) 53.5, (c) 48.27, (d) 36.69.

TL reduced the production losses caused by the common scab (Figure 1d) by 89.78% compared with that in the control. In contrast, TA reduced the production loss by 15.96%.

The total and marketable potato yield in the *Trichoderma* spp. assay is presented in Table 2. No influence of microorganisms was observed on the total yield. However, the microorganisms (TL and TA) significantly improved the marketable yield compared with the control, improving the sale of potato tubers.
Table 2. Potato tuber yield as a function of *Trichoderma* spp.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Total Yield (t ha$^{-1}$)</th>
<th>Marketable Yield (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>62.05 ± 5.68 a</td>
<td>19.76 ± 3.43 c</td>
</tr>
<tr>
<td>TL</td>
<td>65.14 ± 3.48 a</td>
<td>55.88 ± 3.02 a</td>
</tr>
<tr>
<td>TA$^1$</td>
<td>61.02 ± 5.14 a</td>
<td>29.45 ± 7.34 b</td>
</tr>
</tbody>
</table>

\[1\] TA = *T. asperellum*, TL = *T. longibrachiatum*, T = control. Mean values followed by the same letter did not differ significantly in the same column based on Tukey’s test ($p < 0.05$).

3.2. Severity of Common Scab and Potato Production under Biocontrol Agents and Different Soil Organic Matter Content

The damage induced by the common scab on potato tubers in assay 2 using different biocontrol agents and organic matter is presented below. In general, the type of organic material present in the soil influenced the scab incidence on potato tubers (Figure 3a), and plants cultivated on vetch showed an average 30% reduction compared to those grown on palisade grass content.

![Figure 3](image-url)

**Figure 3.** (a) Injured tuber incidence, (b) potato common scab-injured superficial area, (c) disease severity index, (d) and production loss (%) as a function of organic cover and biocontrol agents. ** means significantly in $p < 0.01$, * means significantly in $p < 0.05$, ns means no significant difference. T = control, TL = *T. longibrachiatum*, TA = *T. asperellum*, BSBLTL = *B. subtilis* + *B. licheniformis* + *T. longibrachiatum*, BSEFLP = *B. subtilis* + *E. faecium* + *L. plantarum*. Mean values followed by the same lowercase and uppercase letters did not differ significantly in cover crop and microorganisms, respectively, based on Tukey’s test ($p < 0.05$); CV (%): (a) 9.73, (b) 35.44, (c) 11.58, (d) 17.2.
TA and BSEFLP treatments with vetch organic matter produced the highest reduction (approximately 50%) in the incidence of injured tubers, compared with absolute control (without microorganisms and grown with palisade grass organic matter). TL and BSBLTL treatments with vetch organic matter produced a higher incidence of lesions in tubers than other treatments. However, in tubers produced on palisade grass material, the application of TL and TA resulted in the lowest incidence of injured tubers compared with that of other microorganisms under the same conditions.

Regarding the surface area of the lesions on the potato tubers, tubers grown on vetch mulch showed a 57.5% reduction compared with those grown on palisade grass (Figure 3b). However, BSEFLP with vetch mulch produced a 32% reduction in lesion size compared with the control.

Based on the common scab severity index, vetch reduced disease severity in potato tubers by approximately 30% compared with palisade grass (Figure 3c). Regarding microbial action, a significant reduction in severity was observed only with TA and BSEFLP treatments on vetch plots.

Regarding scab-induced production losses (Figure 3d), 22% further reduced loss was observed in tubers grown on vetch-incorporated soil than in those grown on palisade grass. Regarding microorganisms, the results were similar to those observed for disease severity: lower significant losses were associated with the TA and BSEFLP treatments combined with vetch organic matter, with an average reduction of 33.34% compared with control, resulting in a potential alternative control against potato common scab.

The results exhibited that there was a minimal or non-existent influence of microorganisms, regardless of mulch type (Table 3), on the total potato and marketable potato yield.

### Table 3. Potato tuber yield as a function of organic soil cover and biocontrol agents.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Total Yield (t ha⁻¹)</th>
<th>Marketable Yield (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vetch</td>
<td>Grass</td>
</tr>
<tr>
<td>T</td>
<td>16.03 ± 1.80 Aa</td>
<td>18.25 ± 0.58 Aa</td>
</tr>
<tr>
<td>TL</td>
<td>14.20 ± 1.50 Aa</td>
<td>16.45 ± 0.51 Aa</td>
</tr>
<tr>
<td>TA</td>
<td>14.04 ± 2.00 Aa</td>
<td>17.32 ± 1.75 Aa</td>
</tr>
<tr>
<td>BSBLTL</td>
<td>12.80 ± 2.95 Aa</td>
<td>16.25 ± 3.19 Aa</td>
</tr>
<tr>
<td>BSEFLP</td>
<td>15.85 ± 2.59 Aa</td>
<td>15.59 ± 1.41 Aa</td>
</tr>
</tbody>
</table>

CV (%) = 23.29

TL = *T. longibrachiatum*, TA = *T. asperellum*, BSBLTL = *B. subtilis* + *B. licheniformis* + *T. longibrachiatum*, BSEFLP = *B. subtilis* + *E. faecium* + *L. plantarum*. Mean values followed by the same lowercase and uppercase letters did not differ significantly in cover crop and microorganisms, respectively, based on Tukey’s test (*p* < 0.05).

3.3. Relationship between Common Scab and Yield

Multivariate analysis of the relationships between disease parameters and potato tuber yield after the use of *Trichoderma* spp. revealed that 87% of the data variation was ascribed to two principal components (denoted PC1 and PC2), with the incidence, severity, and common scab-induced losses correlated negatively with marketable yield in PC1 (Figure 4a). However, both parameters showed little correlation with total yield. For biocontrol agents and organic matter (Figure 4b), 89% of the total variation was ascribed to two principal components; although the incidence of injured tubers, lesion size, severity, and losses correlated positively in PC1, loss varied from the other parameters in PC2. In contrast, loss and marketable production were not positively correlated; however, the remaining disease parameters were correlated with marketable production only in PC1. The total yield exhibited an insignificant relationship in PC1 and PC2 for incidence, lesion size, and severity, unlike the loss in PC2.
4. Discussion

Potato common scab poses a challenge to potato growers. Although several practices have been proposed to manage the disease, a number of them have been quite ineffective [1]. Therefore, in this study, the effects of microorganisms and mulch were investigated to expand the knowledge on biocontrol and provide alternative control strategies to ameliorate the damage caused by the disease.

4.1. T. longibrachiatum Reduces Severity and Losses Caused by Potato Common Scab

TL treatment reduced the incidence of scab-affected tubers compared with TA and control (Figure 1a). However, the reduction was significant only in terms of lesion size when compared with the control (Figure 1b); the high variation in the data obtained for tuber plants treated with TA indicated lesions of varied sizes, showing no increasing or decreasing trend. Because of the reduced incidence and size of lesions in the tubercle, TL treatment also significantly reduced the disease severity (Figure 1c), and consequently the damage caused by the bacteria.

The application of bacteria from the genus Bacillus has already been reported to reduce the severity of potato common scab; *Bacillus amyloliquefaciens* and *Bacillus altitudinis* have demonstrated reduced disease severity by up to 50% [20] and 76% [21], respectively. Moreover, a commercial product composed of *Trichoderma* sp. + *B. subtilis* recently demonstrated a reduction in common scab severity by 20–30%, indicating its potential as a control agent. However, the specific *Trichoderma* sp. was neither identified in the previous study, nor tested separately. Hence, the individual contribution of both agents (*Trichoderma* sp. and *B. subtilis*) to the control of common scabs was not ascertained. These results confirm the performance of the TL observed in this study.

The reduction in disease severity possibly reduced the production losses caused by potato common scab (Figure 3d), leading to an increase in the yield of marketable tubers in the experiment comprising TA (Table 2).

The main strategies that may explain the biological control exerted by TL against the disease are parasitism, competition, and antibiosis. In antibiosis, certain volatile compounds, such as butenolides, pyridones, azaphylones, koninginins, steroids, lactones, trichotheccenes, and anthraquinones, which are related to the antibiosis of *Trichoderma* spp., have been reported to inhibit the presence of other microorganisms in the vicinity of *Trichoderma* spp. colonies, and may be the predominant bacterial inhibition method employed by fungi [22]. *Trichoderma* spp. fungi also exhibit aggressive colony growth, rapidly occupying soil spaces and competing with or inhibiting the activity of other microorganisms [23]. Fur-
ther studies are required to unravel the mechanisms underlying the biocontrol of common scabs by *Trichoderma* spp.

### 4.2. Vetch Mulch Reduces Severity and Losses Caused by Potato Scab

A significant reduction in the number of lesion-affected tubers and lesion size was observed in vetch cultivation compared with that in palisade grass in the second assay (Figure 3a,b), although the use of palisade grass caused high data variability owing to the occurrence of heterogeneous lesions among tubers in the treatment plots.

Consequently, the use of vetch organic matter also reduced the disease severity (Figure 3c), which ultimately resulted in reduced production losses from scab-induced damage (Figure 3d).

A possible explanation for the reduction in common scab damage in vetch mulch is the soil pH (approximately 5.2; Table 1), which was lower than that in the palisade grass area. The low C/N ratio of legumes such as vetch can induce microorganisms that compete with plants for N and P to intensely increase the mineralization activity in the organic material present in the soil, increasing the emission of organic acids into the soil and thereby resulting in soil acidification (decrease in soil pH) [24].

Vetch is a leguminous plant that is used as soil cover or green manure. Through nodular bacteria, the plant fixes atmospheric N and provides it to the plants and subsequently to the soil upon decomposition. Vetch improves the physical and chemical properties of the soil, which in turn causes an increase in the population and activity of antagonist microbes, enhancing their action against the negative effects of phytopathogens on plants of agricultural interest [25].

It was previously demonstrated that intercropping vetch with kiwi plants increased the population of fungus, bacteria and actinomycetes in the soil, which in turn increased the activity of catalase, urease, sucrase, and phosphatase in the soil [15]. In addition, a combination of vetch and black oat has been reported to increase microbial biomass activity in a reduced cropping system, compared with the use of black oat alone as a cover crop [26]. The same authors ascribed this outcome to the presence of N, courtesy of legumes in the soil system. Certain leguminous plants have been reported to reduce the severity of the common scab in potato tubers. An example is the mung bean-rattlepod-potato crop rotation system, which leads to an increased population of antagonistic microorganisms such as *Trichoderma* spp. and *Pseudomonas* spp. [14].

Although vetch exerted positive effects on the control of common potato scab damage in this study, the tuber yield was generally lower (Table 3) than that observed with palisade grass (12% higher). A probable explanation could be that H+ released into the system increased the uptake of other harmful cations into the plants, hindering their development. In the vetch-cultivated areas, lower Ca and Mg concentrations were observed, probably lowering the saturation per base (Table 1). The reason for the reduction in tuber production compared with that in control could be the requirement of high-alkalinity soils with good CEC and high V% for potato plants. The results demonstrated that vetch should be adopted for the control of the common scab; however, soil preparation and fertilization should be planned for the addition of vetch in a potato cultivation system.

Therefore, for soil organic matter management, determining the materials to be used and their possible benefits to agricultural production is necessary. It is important to mention that in the final phase of this study (during tuber filling), the plants experienced a severe moth attack (*Tuta absoluta*) that caused serious defoliation and reduced the anticipated harvest, resulting in a premature termination of the experiment and hindering the full productive potential of the plants. Therefore, this event may have prevented us from obtaining further concrete answers regarding tuber production.
4.3. Different Soil Organic Material Influences the Responses of Biocontrol Agents against Common Potato Scab

Biological control, in combination with management practices such as crop rotation or soil cultural succession, can play an important role in reducing disease incidence in commercial crops. Microorganism–organic material interactions can play a major role in biological control because the organic matter of certain plant species can serve as a host for specific types of microorganisms, which can favor either the pathogen or its antagonist, or even inhibit the growth of certain microorganisms [14].

TL combined with TA produced the highest reduction in the incidence of scab-affected tubercles in palisade grass-incorporated areas (Figure 2a), corroborating the results obtained in the previous experiment. Conversely, vetch-infused plots showed the greatest reduction in scab incidence when treated with a combination of TA and BSEFLP, indicating the great potential of these agents under specific conditions.

A few studies on the biocontrol of plant diseases have shown variations in the effects of the biocontrol agents when interacting with crops in different soil covers; for example, the synergy observed between T. harzianum and Miscanthus sp. in the control of Botrytis cinerea in strawberry plants [13].

Bacteria from the genus Bacillus have been shown to be effective in controlling scab [20,21], as they produce antibiotics and form biofilms on plant roots, inhibiting the entry of phytopathogens. Alternatively, they can colonize and induce systemic plant resistance [27]. When used for biocontrol, these bacteria may also interact with soil components, changing or improving the biocontrol response. For example, the application of B. amyloliquefaciens reduces the incidence of diseased banana plants caused by Fusarium oxysporum, not only via direct but also indirect action, such as increasing the population density of Pseudomonas genus bacteria in combination with organic fertilizer (vegetable compound) [28].

The Gram-positive bacteria E. faecium and L. plantarum have also been associated with B. subtilis in composition. Both microorganisms produce lactic acid and are present in the intestinal tract of animals and dairy products. The antagonism of E. faecium is more related to the control of microorganisms that break down food, mainly of dairy origin [29]. Due to its potential biocontrol response, E. faecium may also have contributed to greater responses among bacterial treatments for scabies control. However, the use of L. plantarum as a biocontrol agent is unknown. This report supports the response obtained by applying BSEFLP compounds in vetch-mulched areas.

This effect may reinforce the hypothesis that the performance of antagonistic microorganisms can be strongly influenced by the type of organic material present in the soil, as TL did not have the same reduction effect on the incidence of common scab in potato tubers in areas mulched with palisade grass.

4.4. Biocontrol Agents and Soil Organic Matter Reduced Common Scab-Induced Damage and Maintained the Potential of Plant Production

The study results represent the specific treatment responses (microorganisms, soil cover) against potato scab when compared with the control. To study the effects of the treatments on potato scab in detail, the correlations among the parameters presented in Figure 4 were analyzed and evaluated. The results showed an inverse correlation between the disease parameters and the marketable yield of the tubers, suggesting an improved yield of healthy tubers over those infected with the common scab, probably owing to the influence of the treatments that acted against the damage caused by the disease in both experiments, also demonstrated by previous results. Further studies should be performed to confirm and elucidate the interrelationships between these microorganisms and the type of organic material present in the soil to create better biotechnological strategies for phytopathogen control.
5. Conclusions

*Trichoderma longibrachiatum* (TL) demonstrated greater efficiency in controlling common scab in the first assay that used organic matter from palisade grass alone. In contrast, *T. asperellum* (TA) and *B. subtilis + E. faecium + L. plantarum* (BSEFLP) combined with vetch mulch had greater effectiveness in the second assay, suggesting that soil organic material can influence biological control responses to plant diseases.

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