The effect of cane molasses amendment on biocontrol of frosty pod rot (*Moniliophthora roreri*) and black pod (*Phytophthora spp.*) of cocoa (*Theobroma cacao*) in Panama

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Received 27 February 2006; accepted 12 June 2006
Available online 14 June 2006

**Abstract**

Frosty pod rot (FPR), caused by *Moniliophthora roreri*, and black pod (BP), caused by *Phytophthora* spp., of cocoa (*Theobroma cacao*) cause combined pod losses of more than 80% in Panama. Biological control of both diseases appeared promising in Peru and is desired by certified organic producers in Panama. We evaluated both local and Peruvian fungal antagonists in participatory trials on smallholdings during two complete production cycles. Furthermore, we tested the influence of a 3% v/v cane molasses amendment on biocontrol efficacy, yield and population dynamics of mycoparasites on the cocoa pod. Significant variation was observed between the two years: FPR was more severe in the first year, BP in the second. FPR was significantly reduced by biocontrol agents (BCAs), but not by the molasses amendment. However, BCAs responded differently to molasses in both years. All BCAs reduced inoculum production by *M. roreri* with no consistent effect of molasses. BCAs had a lesser and more variable effect on BP, whereas molasses reduced BP slightly by increasing the efficacy of native antagonists. All BCAs and the molasses amendment enhanced the percentage of healthy pods. Molasses was beneficial to absolute yield, but only one inoculum improved yield significantly in the first year. Populations of a Peruvian *Trichoderma asperellum* isolate remained high for over two months after application to surface-sterilized pods. Molasses had no effect on establishment or survival of this antagonist or recolonization by any native mycoparasite. The reasons for enhanced biocontrol efficacy of the molasses formulation requires further investigation.

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**Keywords:** Antagonism; Biological control; Black pod; *Clonostachys* spp.; Cocoa; Frosty pod rot; Molasses; *Moniliophthora roreri*; Mycoparasisis; *Phytophthora* spp.; *Theobroma cacao*; *Trichoderma asperellum*

1. Introduction

Frosty pod rot (FPR) and black pod (BP) of cocoa (*Theobroma cacao* L.) are caused by *Moniliophthora roreri* (Cif) and several *Phytophthora* spp., predominantly *Phytophthora palmivora* (Butl.) Butl., respectively. In the Bocas del Toro Province, in the northwest of Panama, both diseases are devastating cocoa production, which is in the hands of mostly indigenous smallholders. Combined pod losses generally exceed 80% under traditional management. This represents further aggravation from the 35–75% reported by Somarriba and Beer (1999). Most of the area’s production is certified organic, so that only cultural and biological approaches are viable disease management options. Germplasm with...
resistance to frosty pod, the main disease, is not yet available to growers, although a breeding program with regional trials exists (Phillips-Mora et al., 2005).

Biocontrol of FPR and BP has shown great promise in Peru. Krauss and Soberanis (2001, 2002) used native, broad host-range mycoparasites and found mixtures of them particularly effective, with some yield increases exceeding 15%. Similar attempts in Costa Rica yielded variable results (Batemman et al., 2005; Hidalgo et al., 2003; Krauss et al., 2003).

Very little is known about the effects of nutrient amendments on the biocontrol efficacy of fruit rots. Harman et al. (1992) reported increased biocontrol efficacy of Trichoderma hamatum against botrytis bunch rot of grape when the antagonist was formulated in 0.5% Pelgel, a mixture of carboxymethyl cellulose and gum arabic. Davis et al. (1992) found that Chaetomium globosum formulations containing cellulose improved biocontrol efficacy of pre-harvest apple fruit diseases. Nunes et al. (2001) observed that addition of ammonium molybdate enhanced biocontrol activity of Candida sake against post-harvest problems caused by Penicillium expansum on apple and pear. Somewhat more has been done on leaf surfaces, and it may be possible to draw a comparison, although these play a fundamentally different role in plant carbon partitioning: a carbohydrate source, as opposed to the carbohydrate sink, represented by fruit. Even on leaves, the literature is divided (Sutton and Peng, 1993). Populations of desirable yeasts and bacteria can be encouraged effectively by the application of carbohydrates, amino acids or mixtures of nutrients (Andrews, 1992; Kokalis-Burelle et al., 1992). Filamentous fungi biocontrol agents (BCAs) may benefit from nutrients via enhanced germination, as postulated for Trichoderma spp. (Hjeljord et al., 2001) and C. globosum (Davis et al., 1992), or by boosting antibiotic production, as shown for C. globosum (Andrews, 1992). However, mycoparasitic activity tends to be inhibited by nutrients, especially simple sugars (Hjeljord et al., 2001), whereas for example the plant pathogen Botrytis cinerea is dependent on exogenous nutrients such as sucrose and glucose for germination and penetration (Guetsky et al., 2002). The effect of nutrients on competition between pathogen and antagonist, furthermore, depends on the infection strategy: only necrotrophic pathogens are responsive (Köhler and Fokkema, 1998).

In the present study, we attempted to repeat the Peruvian biocontrol success in Panama, initially with native, Central American antagonists, because we believed these to be best adapted to local agroecological conditions. Only moderate, albeit significant, control levels were obtained in early trials on a research station in Costa Rica (Hidalgo et al., 2003) and later in farmers’ fields (Krauss et al., 2003). Therefore, collaborators opted to also test a Peruvian isolate, Trichoderma asperellum Samuels, Lieckfeldt & Nirenberg Tr-4,2 of known effectiveness (Krauss and Soberanis, 2002), but unknown adaptability to Panamanian conditions, in addition to some mixed, native inocula. In further discussions, the question as to whether biocontrol effectiveness could be enhanced by the addition of nutrients to the formulation was prioritized.

The main objective of these trials was to evaluate Central American and Peruvian biocontrol agents (BCAs) for their effectiveness against FPR and BP under Panamanian smallholder conditions. Furthermore, we tested the effect of nutrients in the form of cane molasses on biocontrol efficacy and antagonist establishment on cocoa pods.

2 Materials and methods

2.1 Participatory on-farm field trials

Participatory field trials were conducted in collaboration with the Cooperativa Cacaotera Bocatorreña (COCABO), based in Almirante, Bocas del Toro Province, Panama. Certified organic member smallholder farmers with an interest in experimentation met with extensionists and researchers to discuss disease control options and prioritized realistic research objectives at the beginning of the trials. Most growers were Ngöbe-Bugle Indians, but descendents of Afro-Caribbean and European settlers were also represented.

Four farms in the communities Junquito and Rio Este Arriba were chosen to install trials in a randomized block design. Relatively large differences existed between trial sites in terms of cocoa germplasm, farmers’ practice and local agroecology. No attempt to standardize these factors or deviate from diverse existing practices was made, because our aim was to arrive at robust recommendations of general applicability. Where within-farm variability was observed for an agroecological feature, treatments were installed along the gradient of this feature, so that all treatments experienced similar exposure. Each treatment was applied to a row of 20 trees per farm. Trials were carried out over two complete growing seasons (May 2001–March 2002 and May 2002–March 2003), with a complete removal of all pods at the beginning of each season. One of the three agents was replaced by another in the second season, resulting in an unbalanced factorial arrangement, as reflected in Figs. 1 and 2 and Tables 1 and 2.

Native Clonostachys spp. were applied in mixtures of up to six isolates per treatment. Mixture MSC contained isolates AMR07, AMR09, AMR48, APP23, and APP43; these were Clonostachys rosea or Clonostachys byssicola, two species that can only be distinguished by molecular means (Schoeters, 2001). Mixture T2 contained C. byssicola isolates AMR37, AMR39, AMR41, AMR42, AMR43, and Clonostachys cf. byssicola AMR38. Mixture T12 contained C. byssicola AMR55, AMR56, AMR57 and again Clonostachys spp. APP23 and APP43. Inoculum was produced on Guata (Krauss et al., 2002). Only the Peruvian T. asperellum Tr-4 was applied as single strain. This fungus was produced on rice (Krauss et al., 2002). Both production
methods yielded over $10^7$ cfu ml$^{-1}$ after extraction for the respective fungi. Extraction was done in the field, based on the previous calibration of each inoculum batch in the laboratory, adjusting inoculum to a total of $10^6$ cfu ml$^{-1}$ with equal proportions of all antagonists in mixtures. The antagonist suspension was applied either in water or with 3% v/v cane molasses (Ingenio Atirro, Turrialba, Costa Rica) at a rate of approximately $3 \times 10^{12}$ cfu ha$^{-1}$, using pressurized (3–4 kg cm$^{-2}$) knapsack sprayers (Protecn 17, Productos Tecnológicos, San Salvador, El Salvador). An absolute con-
Table 1
Number of frosty pod rot-infected pods (per 20 trees) reaching the sporulation stage in four biocontrol plots with or without cane molasses (3% v/v) in the formulation, in Bocas del Toro, Panama, observed over two growing seasons

<table>
<thead>
<tr>
<th>Season</th>
<th>Treatment</th>
<th>Molasses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2001–2002</td>
<td>Control</td>
<td>156.5</td>
<td>88.9</td>
</tr>
<tr>
<td></td>
<td>Mixture MSC</td>
<td>86.7</td>
<td>106.0</td>
</tr>
<tr>
<td></td>
<td>Mixture T2</td>
<td>35.2</td>
<td>68.2</td>
</tr>
<tr>
<td></td>
<td>Mixture T12</td>
<td>71.4</td>
<td>43.5</td>
</tr>
<tr>
<td></td>
<td>Trichoderma asperellum Tr-4</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>2002–2003</td>
<td>Control</td>
<td>64.2</td>
<td>114.4</td>
</tr>
<tr>
<td></td>
<td>Mixture MSC</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>Mixture T2</td>
<td>87.7</td>
<td>76.6</td>
</tr>
<tr>
<td></td>
<td>Mixture T12</td>
<td>51.0</td>
<td>45.1</td>
</tr>
<tr>
<td></td>
<td>Trichoderma asperellum Tr-4</td>
<td>42.9</td>
<td>41.3</td>
</tr>
</tbody>
</table>

na, not applicable; treatment not administered.

Table 2
Number of healthy pods (per 20 trees) harvested in four biocontrol plots with or without cane molasses (3% v/v) in the formulation, in Bocas del Toro, Panama, observed over two growing seasons

<table>
<thead>
<tr>
<th>Season</th>
<th>Treatment</th>
<th>Molasses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2001–2002</td>
<td>Control</td>
<td>90.1</td>
<td>109.2</td>
</tr>
<tr>
<td></td>
<td>Mixture MSC</td>
<td>104.8</td>
<td>133.4</td>
</tr>
<tr>
<td></td>
<td>Mixture T2</td>
<td>90.6</td>
<td>104.2</td>
</tr>
<tr>
<td></td>
<td>Mixture T12</td>
<td>108.9</td>
<td>100.1</td>
</tr>
<tr>
<td></td>
<td>Trichoderma asperellum Tr-4</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>2002–2003</td>
<td>Control</td>
<td>87.5</td>
<td>118.8</td>
</tr>
<tr>
<td></td>
<td>Mixture MSC</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>Mixture T2</td>
<td>74.2</td>
<td>70.3</td>
</tr>
<tr>
<td></td>
<td>Mixture T12</td>
<td>79.1</td>
<td>116.5</td>
</tr>
<tr>
<td></td>
<td>Trichoderma asperellum Tr-4</td>
<td>99.7</td>
<td>105.0</td>
</tr>
</tbody>
</table>

na, not applicable; treatment not administered.

3.3. Frosty pod rot (FPR)

Overall, more FPR was observed in 2001/2002 (51.6%) than in 2002/2003 (42.2%) (P < 0.001). The control agent (P < 0.05), but not molasses (P = 0.691) had a significant effect on FPR incidence. However, the agent interacted significantly with year and year × molasses (both P < 0.001). The interaction agent × molasses narrowly failed to reach significance (\( \chi^2 = 9.41, df = 4 \)). This pattern of interaction means that the overriding factor for biocontrol of FPR was the variability encountered in different years and that this also influenced the reaction of BCAs to molasses, albeit to a lesser extent.

Molasses application alone reduced FPR compared with the absolute control in the first year, but increased FPR in the second year (Fig. 1). In the first year, all agents reduced FPR in the absence of molasses, but only the mixed inoculum T12 did so in the presence of molasses. The mixture MSC was found to be the least effective and was replaced by the single-strain inoculum T. asperellum Tr-4 in the following year. Contrary, in the second year, none of the...
treatments reduced the disease in the absence of molasses, but T12 and Tr-4 did so in the presence of molasses.

For the percentage of FPR-infected pods that reached sporulation, agent was significant \( (P \leq 0.002) \), while molasses had no effect \( (P = 0.731) \) and did not interact with any other factor \( (\chi^2 \leq 8.14, df = 4) \). The two seasons differed significantly \( (P < 0.001) \), but agent and year interacted significantly \( (P < 0.01) \), probably mostly due to the unbalanced design rather than variable behavior of BCAs (Fig. 2). All BCAs, except MSC, reduced the percentage of and, thus, disseminated pathogen inoculum. T12 was most effective, followed by T2 and Tr-4 (Fig. 2). In the second year, a higher percentage (29.8%) sporulated than in the first year (24.9%).

The total number of sporulating pods (Table 1) is a function of disease incidence (Fig. 1) and sporulation incidence (Fig. 2), and is directly related to inoculum to be produced by \( M. \) roreri. All BCAs reduced the number of sporulating pods significantly. Agent \( (P < 0.001) \) and year \( (P < 0.001) \) were significant. Molasses had no simple effect but interacted with agent \( (P < 0.001) \) and agent \( \times \) year \( (P < 0.001) \). The interaction agent \( \times \) year was also significant \( (P < 0.001) \). Again, T12 was most effective, followed by T2, Tr-4 and finally MSC. As for FPR incidence, more pods sporulated in 2001/2002 than in 2002/2003 but, contrary to disease incidence, the BCAs exhibited a clearly differential reaction towards molasses in the two seasons.

In 2001/2002, all agents reduced the number of sporulating pods in the absence of molasses (Table 1). Only MSC failed to do so in the presence of molasses. In 2002/2003, in which MSC was not applied, all agents reduced the number of sporulating pods in the presence of molasses, but T2 was the only treatment that failed to do so in the absence of molasses, whereas this had been the most effective treatment in year one. While molasses application alone reduced the number of FPR-infected pods that reached sporulation compared with the absolute control in the first year, it increased their number in the second year. In 2001/2002, molasses improved the anti-sporulation effect of T12 but seriously compromised the effectiveness of T2. In contrast, in 2002/2003, molasses had no significant effect on any BCA with respect to numbers of sporulating pods (Table 1).

3.2. Black pod (BP)

The incidence of BP behaved almost reverse to FPR incidence. In 2001/2002, less BP (31.2%) was observed than in 2002/2003 (37.5%) \( (P < 0.001) \). Whereas the molasses-only application increased BP incidence compared with the absolute control in the first year, it reduced BP in the following year \( (P < 0.05) \). Overall, only MSC reduced BP, whereas T12, the most effective BCA against FPR, increased it (Fig. 1).

Molasses slightly but significantly \( (P = 0.005) \) reduced BP incidence from 35.0% to 33.5%, but also interacted with agent \( \times \) year \( (P < 0.01) \). The improvement of disease control was due to the beneficial effect of molasses on T2 during the first year. In this year, and only in the presence of molasses, T2 and MSC reduced BP incidence compared with the controls. In the second year, in which MSC was replaced by Tr-4, two treatments, T2 and Tr-4, reduced BP, but this time only in the absence of molasses (Fig. 1).

3.3. Healthy pod yield

The percentage healthy pods (Fig. 1) is a function of losses due to FPR and BP, two diseases that showed contrasting trends. All factors and their first-order interactions, except molasses \( \times \) year, were significant. All BCAs \( (P \leq 0.021) \) and molasses in the formulation \( (P < 0.001) \) increased the percentage of healthy pods. A higher percentage of healthy pods was recorded in the second trial year than in the first one \( (P < 0.001) \). However, the effect of bi-control was more pronounced in 2001/2002, when all agents led to a significant increase in the percentage of healthy pods in the presence and absence of molasses. In 2002/2003, only Tr-4 achieved this, while T12 did so in the presence of molasses only. The addition of molasses increased the percentage of healthy pods for T12 and the control consistently in both years (Fig. 1).

Absolute yield was measured as number of healthy pods harvested (Table 2). This measure is more variable, and BCAs did not significantly increase absolute yield in the second year, although they increased the percentage healthy pods (Fig. 1). In the second year, T2 significantly decreased the number of healthy pods in the presence of molasses. Overall, the molasses formulation was found to be beneficial for yield \( (P < 0.001) \). This beneficial effect was clear for the control (both years), for MSC (year 1), and for T12 (year 2). None of the interactions were significant \( (\chi^2 \leq 5.85) \).

3.4. Effect of cane molasses on establishment of Trichoderma asperellum on cocoa pods and recolonization by native mycoparasites

The surface sterilization prior to application and evaluation did not completely eliminate all cocoa pod-colonizing fungi, some of which are known for their subcuticular or even endophytic growth habit (Ten Hoopen et al., 2003 and references therein). Application of \( T. \) asperellum Tr-4 to surface-sterilized cocoa pods significantly \( (P < 0.001) \) increased the populations of \( Trichoderma \) spp. High population levels (>50%) were maintained for at least five weeks (Fig. 3). The addition of 3% molasses to the formulation had no effect \( (P = 0.445) \).

Other competing fungal genera were largely unaffected by the application of \( T. \) asperellum Tr-4: \( Clonostachys \) spp. \( (P = 0.774) \), \( Fusarium \) spp. \( (P = 0.538) \), \( Gliomastix muro- rum \( (P = 0.052) \) and pooled others \( (P = 0.131) \). The only exceptions were pooled \( Aspergillus \) and \( Penicillium \) spp., which were significantly \( (P < 0.001) \) more abundant on control pods than on \( Trichoderma \)-treated pods. None of these
fungi were influenced by the presence of molasses (0.107 ≤ P ≤ 0.887).

The population dynamics over time are shown in Fig. 3. *Clonostachys* populations appeared reduced after surface sterilization of the pods (week 0), at least in the control, but stabilized at over 90% pod surface colonization after one week, irrespective of treatment. *Fusarium* spp. occurred infrequently and exhibited no clear trend in time. *Gliomastrix murorum*, competitive saprophyte rather than a mycoparasite, was an early pod colonizer, which peaked in week two; later (week four onwards) it was no longer detected. The opposite tendency was observed for *Aspergillus* and *Penicillium* spp.: their populations were very low during the first month after installation of the experiment. After four weeks on uninoculated pods and seven weeks on *Trichoderma*-inoculated pods, population had grown substantially. Other pooled genera fluctuated strongly with a slight increase over time (Fig. 3).

4. Discussion

We observed reduced disease losses and increased yield in the molasses-only control, compared with the absolute control. This suggests that molasses either enhanced naturally occurring BCA populations or acted as a foliar/fruit fertilizer, conveying improved resistance and increasing yield. The later seems less likely, because percentage yield improvement (36.1% and 19.7% in 2001/2002 and 2002/2003, respectively) was greater than absolute yield improvement (21.2% and 13.3% in 2001/2002 and 2002/2003, respectively), i.e. molasses did not increase the net number of pods formed. Enhancement of natural antagonists, especially bacteria and yeasts, has been reported on leaves of cereals and sycamore (Andrews, 1992 and references therein). Population shifts and increases of overall populations of chitinolytic members of naturally occurring epiphytes, associated with the applications of a chitin formulation, decreased the
number of leafspots on leaves of peanut (Kokalis-Burelle et al., 1992). Guetsky et al. (2002) found that, in the presence of sucrose (0.1% w/v), B. cinerea germination on detached strawberry leaves was reduced from 56.7% to 30.7% by the addition of leucine. However, Hjeljord et al. (2000) reported increased strawberry rot (Botrytis cinerea and Mucor piriformis) on plants sprayed with sucrose (1% w/v) compared with the water control. We found no evidence of antagonistic filamentous fungi benefiting from cane molasses amendment. Bacteria and yeasts merit a closer look. The survival of some antagonistic bacteria on banana (Musa AAA) leaves was enhanced by cane molasses and other nutrient amendments in greenhouse assays (Ruíz-Silveira et al., 1997a). However, under field conditions, cane molasses alone increased Black Sigatoka (Mycosphaerella fijiensis) infection and, as an amendment with bacterial BCAs, did not influence biocontrol efficacy (Ruíz-Silveira et al., 1997b), while biocontrol effected by yeasts was enhanced by complex nutrient amendments (Arango, 2000). On detached strawberry leaves, Guetsky et al. (2002) found that the effects of nutrient amendments on biocontrol efficacy of a mixture of Pichia guillermondii and Bacillus mycoides were erratic. Different supplements had different effects with some nutritional supplements almost nullifying the effects of the control agents and some enhancing it greatly.

Molasses is a complex nutritional supplement which might contribute to the inconsistent effects on biocontrol. The total carbohydrate content of the molasses was determined as being 59.1% w/w by the laboratory of the Universidad de Costa Rica, using the Lane–Eynon method. This is lower than the average 72.5% w/w commonly found in cane molasses (Oregon State University, undated). Typically, cane molasses has a higher carbohydrate content than beet molasses and a ratio of C12 sugars to other sugars of 1.7, as compared with a ratio of 105 for beet molasses. Cane molasses contains approximately 7.5% w/w nitrogenous compounds, beet molasses twice that much (15.6% w/w). Other compounds are in a similar range (Oregon State University, undated).

Cane molasses amendment had no consistent effect on biocontrol efficacy. Instead, the various treatments responded differently in the two trial seasons. Nutrient deposits available to microbes on leaves are highly variable and depend on a multitude of factors (Andrews, 1992). These merit investigation, especially on fruit, as information there is extremely scarce, although fruit are the commercial product of the majority of crops. While T. asperellum Tr-4 appeared indifferent to molasses both, in biocontrol and field survival trials, a generalization for other fungi is not possible. Some agents responded positively, and yield, on the whole, benefited from the molasses amendment.

Fungistasis is the inhibition of germination and growth of fungal cfus caused by nutrient stress. In addition to conidia, the BCA extraction procedures yielded some hyphal fragments, which tend to be less susceptible to fungistasis (Hjeljord and Tronsmo, 1998). It should also be noted that inoculum of T. asperellum Tr-4 was extracted from its rice substrate in the field, immediately prior to application, which may have provided some exogenous nutrients in the form of rice particles in the application mixture, whereas Clonostachys spp. were extracted from the inert Guata (Krauss et al., 2002). Fresh Trichoderma conidia are less dependent on exogenous nutrients than older ones. However, different species of Trichoderma respond differently to different types of nutrients (Nelson et al., 1988). No study so far has covered T. asperellum. In better investigated soil systems, Trichoderma spp. are relatively sensitive to fungistasis compared with other soil fungi, but not extremely so. Fungistatic sensitivity is negatively correlated to spore size (Steiner and Lockwood, 1969). Amongst Trichoderma spp., the conidia of T. asperellum are in the average range, with dimensions of (2.8–) 3.4–3.6(−7.0) × (2.4–) 3.4–(6) μm (Samuels et al., undated). Various other Trichoderma spp. cope with nutrient stress better under acidic conditions (pH 4.3) than neutral ones (Danielson and Davey, 1973), but such in vitro simulations are not necessarily representative of germination on natural substrates (Nelson et al., 1988). How fungistasis may affect the efficacy of the applied BCAs, and specifically T. asperellum Tr-4, remains to be studied in more detail.

Bateman et al. (2005) speculated that residual cane molasses from the fermentation process to mass-produce Clonostachys spp. inoculum (Krauss et al., 2002) may have negatively affected the competition between M. roreri and its antagonists in trials in Costa Rica. In our trials in Panama, the necrotrophic pathogen P. palmivora showed no clearer response to BCAs formulated in molasses than M. roreri, a biotroph during the early stages of its infection cycle (Evans et al., 2002). Instead, an opposite trend for these two pathogens was noted. This applied to FPR incidence, presumably dominated by the biotrophic stage, as well as to sporulation of infected pods, presumably dominated by the saprophytic stage of M. roreri. Thus, in our pathosystems, we could not reproduce the observation of Köhl and Fokkema (1998) that necrotrophic pathogens benefit more from nutrient amendments than biotrophs. Furthermore, none of the facultative mycoparasites and other saprophytic pod fungi responded measurably to molasses amendments during recolonization.

Only T. asperellum Tr-4 reduced FPR and BP simultaneously. Although only data for one year are available for this BCA, these are promising. This Peruvian isolate, applied in water, was also the best treatment in participatory on-farm trials in neighboring Costa Rica, where a 34% yield increase was recorded in 2001/2002, while the local mixture T2 improved yield by 21% (Krauss et al., 2003). For comparison, Krauss and Soberanis (2002), in Peru, harvested an additional 19.7% of healthy pods with T. asperellum Tr-4 applications. This indicates that T. asperellum Tr-4 adapted well to Central American conditions. On the other hand, Bateman et al. (2005) observed no effect on yield by either T. asperellum Tr-4 or a mixture of three
Peruvian C. hyssicola strains with T. asperellum Tr-4 in a Costa Rican experimental station. Unfortunately, the authors did not analyze disease incidence data. The large variability both, across seasons and within a relatively small geographic area, suggests that important ecological factors influencing the pathogen—antagonist interaction on the cocoa pod are yet to be elucidated before we can improve biocontrol efficacy in an informed and targeted manner.

Acknowledgments

This work was funded by USDA-ARS, DGIS, Cocoa Research UK, and the OLIN Foundation, and was managed by CABI Bioscience, CATIE, and COCABO. We are most grateful to all participating farmers and to Robert Mack for their enthusiasm and thought-provoking discussions. We also thank the University of Bath for support through their student placement program. Maribel Mora, Armando Portugete and Miguel Sanabria provided technical assistance.

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