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Control of cacao *(Theobroma cacao)* diseases in Santo Domingo de los Tsachilas, Ecuador[1]

Control de enfermedades del cacao *(Theobroma cacao)* en Santo Domingo de los Tsáchilas, Ecuador

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Abstract

Introduction. Ecuador occupies the fourth place in cocoa exports with 293,487 tons per year, produced on 559,617 hectares. However, its yield per hectare is low mainly due to the presence of pathogens that affect the pods. **Objective.** To evaluates different methods of control of pathogens of the *Theobroma cacao* cv 'CCN-51' pod. **Materials and methods.** The work was carried out in Luz de America, Santo Domingo de los Tsachilas, Ecuador, between 2016 and 2017. The treatments were the result of the combination of cultural practices + two fungicides (Chlorothalonil and Pyraclostrobin) + one biofungicide Serenade® (*Bacillus subtilis* QST713), with and without fertilizers. In total, 16 treatments were evaluated with 3 replicates or blocks, installed in a commercial cocoa plantation cv 'CCN-51' and under a Randomized Complete Block Design (RCBD). **Results.** The use of fungicides (chemical and biological), decreased the incidence of moniliasis (*Moniliophthora roreri*), black pod rot (*Phytophthora* spp.), and cherelle wilt; but the application of fertilizers did not increase the effectiveness of these products. Treatment with only cultural practices did not decrease the final incidence of moniliasis, nor of brown rot, in contrast, the final incidence of cherelle wilt increased. The number of pods and the yield were not directly related and the highest yield of fermented and dry cocoa, corresponded to T9 [Cultural labors + Serenade® (0.2 kg ha^{-1}) (every 15 days) + Fertilizer (0.3 kg ha^{-1}) + Fertilizer (1 kg plant^{-1})], a treatment that also had the highest net income per hectare. **Conclusion.** Chemical and biological control can manage cocoa pods pathogens. The integration of both control methods allowed the cocoa producer to obtain greater income.

Keywords: *Moniliophthora roreri*, *Phytophothora*, cherelle wilt, *Bacillus subtilis*, Pyraclostrobin.

Resumen

Introducción. Ecuador ocupa el cuarto lugar en exportaciones de cacao con 293 487 toneladas al año, producidas en 559,617 hectáreas. Sin embargo, su rendimiento por hectárea es bajo debido principalmente a la presencia de patógenos que afectan la mazorca. **Objetivo.** Evaluar métodos de control de patógenos de la mazorca de *Theobroma cacao* cv 'CCN-51'. **Materiales y métodos.** El estudio se llevó a cabo en Luz de América, Santo Domingo de los Tsáchilas, Ecuador, entre 2016 y 2017. Los tratamientos fueron el resultado de la combinación de labores culturales + dos fungicidas (Clorotalonil y Pyraclostrobin) + un biofungicida Serenade® (*Bacillus subtilis* QST713), con y sin fertilizantes. En total se evaluaron dieciséis tratamientos con tres réplicas o bloques, instalados en una plantación comercial de cacao cv 'CCN-51' y bajo un diseño de bloques completos al azar (DBCA). **Resultados.** El uso de fungicidas (químicos y biológicos), disminuyó la incidencia de la moniliasis (*Moniliophthora roreri*), pudrición negra de la mazorca (*Phytophthora* spp.) y cherelle wilt; pero la aplicación de fertilizantes no aumentó la efectividad de estos productos. El tratamiento solo con labores culturales, no disminuyó la incidencia final de la moniliasis, tampoco de la pudrición negra de la mazorca, en cambio, aumentó la incidencia final del cherelle wilt. El número de mazorcas y el rendimiento no estuvieron directamente relacionados y el mayor rendimiento de cacao fermentado y seco, correspondió al T9 [labores culturales + Serenade® (0,2 kg ha^{-1}) (c/ 15 días) + fertilizante, (0,3 kg ha^{-1}) + abono (1 kg planta^{-1})], tratamiento que también tuvo el mayor ingreso neto por hectárea. **Conclusión.** El control químico y biológico pueden combatir patógenos de la mazorca de cacao. La integración de los dos métodos de control permitió al productor obtener mayores ingresos.

Palabras clave: *Moniliophthora roreri*, *Phytophothora*, cherelle wilt, *Bacillus subtilis*, Pyraclostrobin.

Introduction

Cacao (*Theobroma cacao* L.) is a specie native to South America (Motamayor et al., 2002) and its cultivation is important worldwide. Like other cultivated plant species, cacao can be attacked by diseases that negatively impact production, generating losses of approximately 30 % (Jaimes & Aranzazu, 2010).

In Ecuador, it is an important agricultural product since it occupies the fourth place in agricultural exports with 293,487 tons per year, produced in 559,617 hectares. But, despite its economic importance, the yield of cacao is low (250 kg ha^{-1}), which reflects the various problems that the crop has, such as diseases that directly affect the cacao pods. Among these, the Moniliasis caused by *Moniliophthora roreri* stands out, which can cause losses of up to 90 % of production (Bailey et al., 2017). Another problem is the so-called "black pod rot", caused by the genus *Phytophthora* (Ali et al., 2017; International Cacao Organization, 2015) and that can cause losses up to 30 % (Acebo et al., 2012). A third additional, but no less important problem is premature death of the cacao pods, commonly known as cherelle wilt. The causes of this problem are still unknown, although some researchers associate it with the nutritional status of the plant (Bradnan, 2015).

The presence of moniliasis (*M. roreri*), black pod rot (*P. palmivora*), and witches broom (*Moniliophthora perniciosa*) has already been reported in Santo Domingo de los Tsachilas, Ecuador. One study indicate that 49.4 % of producers in that area, reports moniliasis as the most important disease, followed by black pod rot (3.7 %) and "witches' broom" (1.2 %) (Anzules et al., 2018). However 43.2 % of producers report the attack of more than one disease and these can affect up to 50 % of pods production (Ortíz et al., 2015; Sánchez et al., 2015). The cherelle wilt is a lesser-known phenomenon that affects approximately 60 % of young cocoa pods (Bradnan, 2015).

In Mexico, various fungicides were evaluated *in vitro* and found that *M. roreri* was sensitive to systemic fungicides (azoxystrobin, trifloxystrobin, tebuconazole and propiconazole), as well as to protectants (copper sulfate, copper hydroxide, cuprous oxide, copper oxychloride and calcium polysulfide) (Torres et al., 2019). *In vivo*, an application of azoxystrobin, trifloxystrobin, tebuconazole or propiconazole, supplemented with copper hydroxide, significantly decreased the incidence of moniliasis (Torres et al., 2019). In Peru, the application of chlorothalonil, copper hydroxide, and cuprous oxide controlled moniliasis with similar effectiveness and the incidence was lower than the non-treated control. Also, these treatments had the highest cocoa yields and the highest rates of economic return (Jáuregui, 2001). In Ecuador, a Cu + Mancozeb sulfate treatment reduced the area of progress of the disease curve as compared to a treatment in which diseased pods were removed every 15 days (Estrella & Cedeño, 2012).

The uses of bacteria, especially *Bacillus* spp. and *Pseudomonas fluorescens*, has begun to receive attention in recent years for the control of cacao diseases, although less than the use of antagonist fungi (Vera et al., 2018). Different endospore-forming bacteria have been identified in cacao plant tissues without causing any detrimental effect to their host (Vera et al., 2018). Some of these bacteria were active against *P. capsici*, *M. roreri*, and *M. perniciosa*. Furthermore, many *Bacillus* spp. have a chitinolytic capacity and could antagonize phytopathogenic fungi such as *M. roreri* and *M. perniciosa* (Vera et al., 2018). The chitinolytic capacity of *Bacillus* spp. are probably less effective against black pod rot, because it is not a fungus and has cell walls composed mainly of cellulose. The use of bacteria for diseases control in cacao is still incipient, however, given the interesting results presented in the few available documents, it certainly deserves more attention (Vera et al., 2018).

The cherelle wilt is the premature death of the pods and can occur up to 50 days after pollination. The origin of this physiological disorder is poorly understood and is considered to be a failure in embryogenesis associated with nutritional deficiencies (Bradnan, 2015). It is also associated with an increase in the levels of the intermediates of the tricarboxylic acid cycle and a decrease in the main metabolites (Melnick et al., 2013). The published information on the effect of fungicides on this anomaly presents contradictory results and in recent years little research has been done on the subject. For example, cuprous oxide exhibits a significant increase in cherelle wilt and, to a lesser extent, Captafol (Murillo & Gonzales, 1984). Furthermore, Chlorothalonil and Triphenyl tin acetate did not significantly inhibited this physiological disorder (Murillo & Gonzales, 1984). More recently, in Ecuador, it was found that the application of copper sulfate, both to the soil and to the foliage, decreased the abortion of cacao pods (Bajaña, 2016).

Few studies have been carried out to evaluate the integration of several control measures in a unified program referred to as integrated system of disease management (Acebo et al., 2012). Significant reduction in the incidence of the moniliasis were reported with the use of an integrated management program (Ortíz et al., 2015; Maldonado, 2015).

CCN-51 is a cultivar native to Ecuador, it occupies approximately 70 % of the planted area and the crop yield is between 2000 to 3000 kg ha^{-1} (Asociación Nacional Exportadores de Cacao e Industrializados del Cacao, 2018). It is considered a self-compatible genotype, moderately resistant to witches' broom, moderately susceptible to moniliasis and susceptible to black pod rot (García, 2010). It is, also attacked by fungus that affect the pods, so it is necessary to test adequate control methods to avoid significant losses at harvest time.

The study aimed to evaluate different diseases control methods of the *Theobroma cacao* cv 'CCN-51' pod.

Materials and methods

This research was carried out in a five-year-old commercial cocoa (*Theobroma cacao)* cv 'CCN-51' plantation. The plantation is located at an altitude of 272 meters above sea level, in the Luz de America parish (0 ° 26' 28'' S, 79 ° 19' 23'' W) in the province of Santo Domingo de los Tsáchilas, Ecuador. It is an area with a humid tropical climate, with an annual rainfall of 2800 mm and an average temperature of 23 ° C.

During the study period (April-2016 and March-2017) the highest temperature values were recorded between the months of January to May; while the period of greatest precipitation was between January and April. The experiment was conducted under a Randomized Complete Block Design (RCBD) with 16 treatments and 3 replicates or blocks.

The experimental units consisted of 210 m^2 plots, each with 15 cocoa plants (3 rows of 5 plants) with a distance of 3.5 m x 3.5 m. To avoid the edge effect, the data was taken from the three central plants in each experimental unit. The technicians recomendation for the treatments design was followed (Table 1). In general, these are a

Table 1. Treatments applied in a trial for pathogen control in cocoa (*Theobroma cacao)* cv 'CCN-51' in Luz de América, Santo Domingo de los Tsachilas (Ecuador), 2016-2017.

Cuadro 1. Tratamientos aplicados en ensayo para control de enfermedades en cacao (*Theobroma cacao*) cv 'CCN-51 en Luz de América, Santo Domingo de los Tsáchilas, Ecuador, 2016-2017.

Treatments	General description	Specific description	Control method
T1	Group 1 (High frequency chemical fungicides + increased fertilization)	CT + CLO (1 kg ha^{-1}) (every 15 days) + PYRA (0.5 kg ha^{-1}) (every 90 days) + FERT (0.3 kg $plant^{-1}$) + MAN (1 kg $plant^{-1}$)	Chemical
T2		CT + CLO (1 kg ha^{-1}) (every 15 days) + PYRA (0.5 kg ha^{-1}) (every 90 days) + FERT (0.4 kg $plant^{-1}$) + MAN (2 kg $plant^{-1}$)	
T3		CT + CLO (1 kg ha^{-1}) (every 15 days) + PYRA (0.5 kg ha^{-1}) (every 90 days) + FERT (0.5 kg $plant^{-1}$) + MAN (3 kg/plant)	
T4		CT + CLO (1 kg ha^{-1}) (every 15 days) + PYRA (0.5 kg ha^{-1}) (every 90 days)	
T5	Group 2 (Low frequency chemical fungicides + increased fertilization)	CT + CLO (1 kg ha^{-1}) (every 30 days) + PYRA (0.5 kg ha^{-1}) (every 180 days) + FERT (0.3 kg $plant^{-1}$) + MAN (1 kg $plant^{-1}$)	Chemical
T6		CT + CLO (1 kg ha^{-1}) (every 30 days) + PYRA (0.5 kg ha^{-1}) (every 180 days) + FERT (0.4 kg $plant^{-1}$) + MAN (2 kg $plant^{-1}$)	
T7		CT + CLO (1 kg ha^{-1}) (every 30 days) + PYRA (0.5 kg ha^{-1}) (every 180 days) + FERT (0.5 kg $plant^{-1}$) + MAN (3 kg $plant^{-1}$)	
T8		CT + CLO (1 kg ha^{-1}) (every 30 days) + PYRA (0.5 kg ha^{-1}) (every 180 days)	
T9	Group 3 (Biological fungicide + growing fertilization)	CT + Serenade® (0.2 kg ha^{-1}) (every 15 days) + FERT (0.3 kg $plant^{-1}$) + MAN (1 kg $plant^{-1}$)	Biological
T10		CT + Serenade® (0.2 kg ha^{-1}) (every 15 days) + FERT (0.4 kg $plant^{-1}$) + MAN (2 kg $plant^{-1}$)	
T11		CT + Serenade® (0.2 kg ha^{-1}) (every 15 days) + FERT (0.5 kg $plant^{-1}$) + MAN (3 kg $plant^{-1}$)	
T12		CT + Serenade® (0.2 kg ha^{-1}) (every 15 days)	
T13	Group 4 (Cultural work + growing fertilization)	CT + FERT (0.3 kg ha^{-1}) + MAN (1 kg $plant^{-1}$)	Cultural
T14		CT + FERT (0.4 kg ha^{-1}) + MAN (2 kg $plant^{-1}$)	
T15		CT + FERT (0.5 kg ha^{-1}) + MAN (3 kg $plant^{-1}$)	
T16		CT (Commercial control)	

CT: Cultural tasks (cultural control of weeds + maintenance pruning + sanitary pruning + elimination of diseased pods) / CT: labores culturales (control cultural de malas hierbas + poda de mantenimiento + poda sanitaria + eliminación de vainas enfermas).
CLO (Clorotalonil), PYRA (Pyraclostrobin), Fertilizer (FERT: 18 N - 6 P_2O_5 - 22 K_2O - 3 MgO- 3,8 S - 0,53 B) / CLO (Clorotalonil), PYRA (Piraclostrobin), fertilizante (FERT: 18 N - 6 P_2O_5 - 22 K_2O - 3 MgO- 3,8 S - 0,53 B).
Maintenance (MAN): / mantenimiento (MAN): N (2,1 %) – P (1,55 %) - K_2O (1,8 %) – Ca O (2,8 %).

combination of cultural tasks (sanitary pruning + removal of diseased fruits), with the use of synthetic fungicides (Chlorothalonil or Pyraclostrobin) and a biofungicide Serenade® (*Bacillus subtilis* QST713), in addition to fertilization. In the commercial control treatment, only cultural work was carried out.

The soil analysis was carried out at the Pichilingue Tropical Experiment Station and the methods used were those recommended by the Soil Science Society of America (1982). The soil was sandy loam, with a pH of 5.5 and an available phosphorus content of 14 mg kg^{-1}. The K level was 0.22 $cmol_{(+)}$ kg^{-1}, 6 $cmol_{(+)}$ kg^{-1} of Ca and 0.70 $cmol_{(+)}$ kg^{-1} of Mg. The contents of other elements in the soil were: 4 mg kg^{-1} of S, 2.5 mg kg^{-1} of Zn, 7.2 mg kg^{-1} of Cu, 141 mg kg^{-1} of Fe, 5.4 mg kg^{-1} of Mn, and 0.46 mg kg^{-1} of B. Mechanical weed control, maintenance and sanitary pruning were carried out every 90 days and diseased pods were eliminated every 15 days. To improve the availability of nutrients, agricultural lime [$Ca(OH)_2$] was applied to each plant (0.5 kg pl^{-1}) at the beginning of the experiment. The variables evaluated monthly were: number of healthy pods, number of pods affected by *M. roreri*, number of pods affected by *Phytophthora* spp., number of pods with cherelle wilt. At harvest, the yield of fresh cocoa beans (cacao baba) and the yield of fermented and dry cocoa were evaluated. To determine the incidence of moniliasis, black pod rot and cherelle wilt, the formula NI = [MD / MT] x 100 (where MD: Number of fruits damaged and MT: Number of total fruits) was used. For the fresh weight (PF = cacao baba), the pods were collected, the beans were extracted and weighed. The weight of fermented and dry cocoa (PS), with 7 % humidity, was estimated with the formula: PS = FP x 0.4, the same that is used commercially in Ecuador. The data were subjected to Variance Analysis (ANOVA) and to compare the mean between the different treatments a Tukey test (95 %) was used.

Results

Effect of treatments on moniliasis

In this work, no significant statistical differences were found between the treatments studied for the incidence of moniliasis in the first evaluation, however there was statistical differences in the last evaluation($p\leq0.05$). Most of the treatments with fungicides had a positive effect on disease control, the final incidence was almost always lower than the initial incidence (Figure 1A). When comparing T4 with T1, T2, and T3, no improvement was observed in the control of the disease due to the increase in fertilization; but T1 and T2 stood out, which decreased the final incidence in a greater proportion than the other treatments. When comparing the other group of chemical control treatments (T8 with T7, T6, and T5), no improvement was observed in the control of the disease due to the increase in fertilization, highlighting T8, a treatment that did not receive fertilization (Figure 1A). When the group of biological control treatments (T12 with T11, T10 and T9) is compared, it is found that most of the treatments also had a positive effect on the control of moniliasis, although the final incidence was almost always lower than the initial incidence, with the exception of T12 whose final incidence was higher than the initial one. Nor was an improvement in disease control found when fertilization was increased (Figure 1A). In the group of cultural control treatments (T16 with T15, T14 and T13), no control of this disease was reported. In most of these, the initial and final incidence were similar, and even in T16, there was an increase in the final incidence (Figure 1A).

Effect of treatments on black pod rot

In this trial, no statistically significant differences were found between the treatments studied in the first evaluation of the experiment, however there was statistically differences in the last evaluation ($p\leq0.05$). Most of

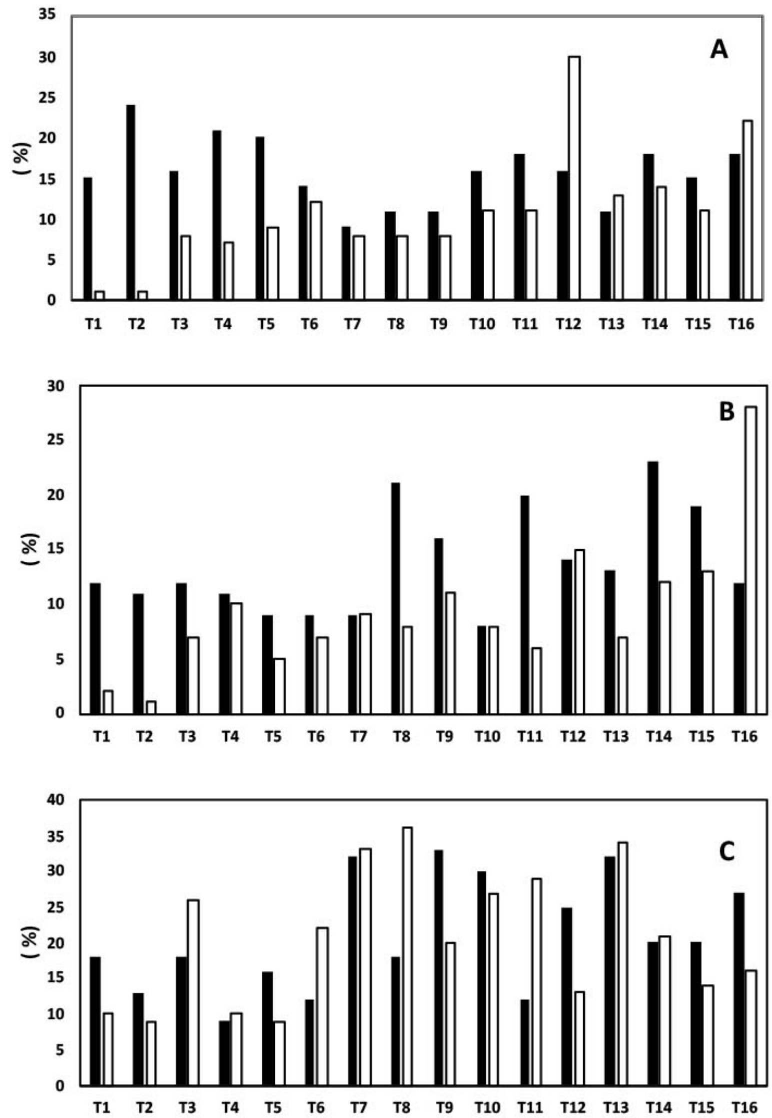

Figure 1. Incidence at the beginning (black bar) and end of the trial (white bar) of *Moniliophthora roreri* (A), *Phytophthora* sp. (B) and cherelle wilt (C) in cocoa (*Theobroma cacao)* cv 'CCN-51 experiment, in Luz de America, Santo Domingo de los Tsachilas, Ecuador. 2016-2017.

Figura 1. Incidencia al inicio (barra negra) y final del ensayo (barra blanca) de *Moniliophthora roreri* (A), *Phytophthora* sp. (B) y cherelle wilt (C), en un experimento en una plantación comercial de cacao (*Theobroma cacao)* cv 'CCN-51, en Luz de América, Santo Domingo de los Tsáchilas, Ecuador. 2016-2017.

the treatments with fungicides had a positive effect on the control of the disease, which was reflected in the fact that the final incidence was almost always lower than the initial incidence (Figure 1B). When comparing T4 with T1, T2 and T3, only T1 and T2 showed improvements in the control of the diseases due to the increase in fertilization.

In the other group of chemical control treatments (T8 with T7, T6, and T5), they did not show improvements in diseases control due to increased fertilization; however, T5 and T8 stood out, which reduced the incidence in a greater proportion (Figure 1B). With the group of biological control treatments (T12 with T11, T10, and T9), it was found that only the treatments T9 and T11 had a positive effect on the control of the black pod rot. The final incidence was lower than the incidence initial, the exceptions were T10 and T12, which had no effect in the initial and final incidence as these were similar. Nor was an improvement in the control of the disease found, when fertilization was increased (Figure 1B). In the group of cultural control treatments (T16 with T15, T14, and T13), T16 was the only one that did not report a decrease in the final incidence of the disease caused by *Phytophthora*. In the other treatments, the final incidence was lower than the initial one, as shown in Figure 1B.

Effect of the treatments on the cherelle wilt

No statistically significant differences were reported between the treatments studied for the incidence of cherelle wilt in any evaluation during the experiment ($p \leq 0.05$). Treatments T1, T2 and T5 with fungicides had a positive effect on the control of this anomaly. The final incidence was always lower than the initial incidence (Figure 1C). When comparing T4 with T1, T2, and T3, no improvement was observed in the control of the cherelle wilt due to the increase in fertilization, even the treatment (T3) increased the final incidence in a greater proportion than the T4 treatment. When the other group of chemical control treatments (T8 with T7, T6 and T5) was compared, only in T5 was an improvement in the control of the cherelle wilt observed. In contrast, treatments T6, T7, and T8 increased the incidence despite having received fungicide applications and fertilization (T6 and T7), as shown in Figure 1C. When analyzing the group of biological control treatments (T12 with T11, T10, and T9), it was found that all the treatments with the exception of T11, had a positive effect on the control of the cherelle wilt (Figure 1C). But no clear improvement was found in the control of this anomaly, when fertilization was increased. T12 was the treatment that most decreased the final incidence, compared to the other treatments (Figure 1C). In the group of cultural control treatments (T16, T15, T14, and T13), the final incidence at T13 and T14 was higher than the initial incidence (Figure 1C).

Effect of treatments on number of pods, yield and income

In this trial, there was no clear effect of control types on the number of healthy cacao pods, but a chemical control treatment (T1) had the highest number of healthy cacao pods, being higher than T15, which had the least amount. Both were statistically similar to most of the evaluated treatments (Figure 2A). While the lowest, corresponded to a cultural control treatment, more fertilization and organic matter (T15), as shown in Figure 2B. The economic analysis (Table 2) shows that the treatment that would allow to have the highest net income would be T9 [Cultural labors + Serenade® (0.2 kg ha^{-1}) (every 15 days) + Fertilizer (0.3 kg $plant^{-1}$) + Fertilizer (1 kg $plant^{-1}$)], followed by T6 and T4, which correspond to the group of chemical control treatments.

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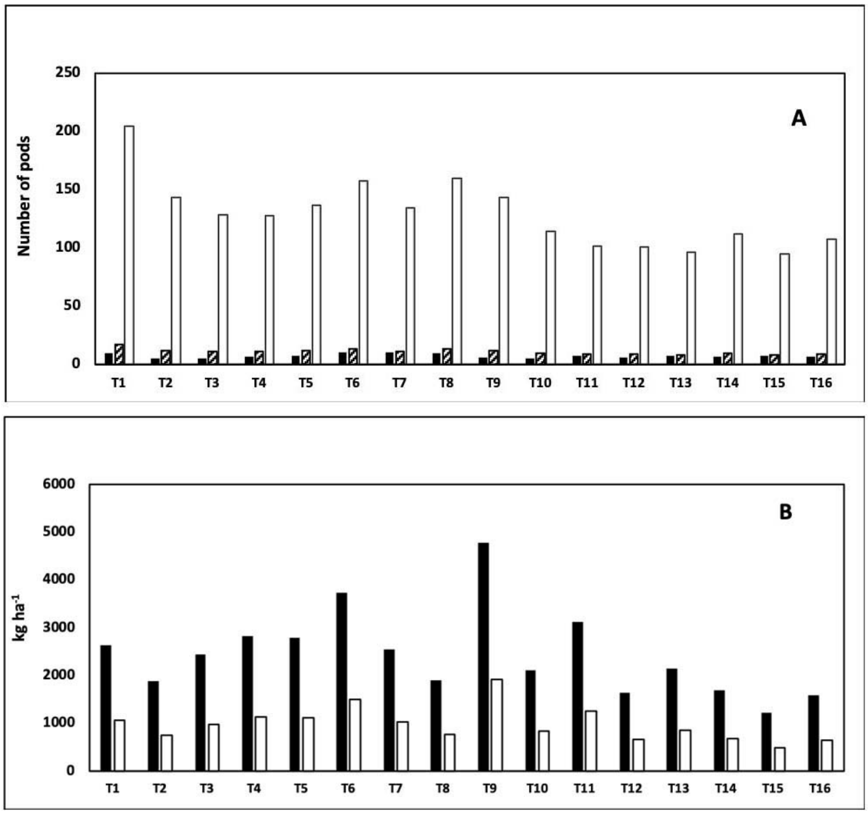

Figure 2. Number of pods (A) per cocoa tree (*Theobroma cacao)* cv 'CCN-51' at the beginning of the trial (black bar), average per tree during the trial (hatched bar) and total per tree during the study period (white bar). Cocoa yield (B) in slime (black bar), fermented and dry (white bar), in Luz de America, Santo Domingo de los Tsachilas (Ecuador), 2016-2017.

Figura 2. Número de mazorcas (A) por árbol de cacao (*Theobroma cacao)* cv 'CCN-51' al inicio del ensayo (barra negra), promedio por árbol durante el ensayo (barra con trama) y total por árbol durante el periodo de estudio (barra blanca). Rendimiento de cacao (B) en baba (barra negra), fermentado y seco (barra blanca), en Luz de América, Santo Domingo de los Tsáchilas, Ecuador, 2016-2017.

Discussion

The results of the present study show the possibilities of using chemical control for the management of moniliasis and black pod rot in the study area. But there are researchers who said that exist doubts about the effectiveness of chemical control (Jaimes & Arazanzu, 2010) and it should only be used in plantations where high yields are certain (Jáuregui, 2001), due to its high costs (Jaimes & Aranzazu, 2010). The most effective products against this pathogen have yet to be selected (Torres et al., 2019). The truth is that several reports corroborate the effectiveness of fungicides such as copper-based products, Chlorothalonil, Azoxystrobin, and Difenoconzale (Calva, 2016; Jáuregui, 2001; Morales, 2001) for the control of *M. roreri and Phytophthora sp*.

The effectiveness of the biological control of the moniliasis and black pod rot in this research corroborates previous references such as those by Koranteng & Awuah (2011), who isolated and characterized eight antagonist rhizobacteria of *P. palmivora* and demonstrated that products based on bacteria and their cell-free broths could be used as biofungicides to control the black pod rot of the fruit in cacao. Other studies found that some of these

Table 2. Economic analysis of the treatments studied for the control of pathogens of the cocoa pod (*Theobroma cacao)* cv 'CCN-51' in Luz de America, Santo Domingo de los Tsachilas, Ecuador. 2016-2017.
Cuadro 2. Análisis económico de los tratamientos estudiados para el control de enfermedades de la mazorca de cacao (*Theobroma cacao)* cv 'CCN-51', en Luz de América, Santo Domingo de los Tsáchilas, Ecuador. 2016-2017.

	Treatments															
Concept	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**	**T16**
Yield (kg ha^{-1})	1053.4	752.9	977.7	1126.1	1116.3	1487.5	1017	755.3	1911.7	839.5	1244.7	656.9	856.9	674.9	485.1	633
Adjusted return (-5 %)	1000.73	715.26	928.82	1069.8	1060.49	1413.13	966.15	717.54	1816.12	797.53	1182.47	624.06	814.06	641.16	460.85	601.35
Selling price (USD x kg)	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
1. Gross income (USD x ha)	**1981.45**	**1416.21**	**1839.06**	**2118.20**	**2099.77**	**2798.00**	**1912.98**	**1420.73**	**3595.92**	**1579.11**	**2341.29**	**1235.64**	**1611.84**	**1269.50**	**912.48**	**1190.67**
Cultural work (USD x ha)	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
Fungicides (USD x ha)	240	240	240	240	120	120	120	120	144	144	144	144				
Fertilizers (USD x ha)	123	164	205		123	164	205		123	164	205		123	164	205	
Fertilizers (USD x ha)	41	82	133.1		41	82	133.1		41	82	133.1		41	82	133.1	
Labor for application (USD x ha)	210	120	210		210	120	210		210	120	210		30	30	30	
2. Total cost / treatment (USD x ha)	**869**	**861**	**1043.1**	**495**	**749**	**741**	**923.1**	**375**	**773**	**765**	**947.1**	**399**	**449**	**531**	**623.1**	**255**
3. Net income	**1112.45**	**555.21**	**795.96**	**1623.20**	**1350.77**	**2057.00**	**989.88**	**1045.73**	**2822.92**	**814.11**	**1394.19**	**836.64**	**1162.84**	**738.50**	**289.38**	**935.67**

bacteria were active against *P. capsici* (Vera et al., 2018). However, chitinolytic *Bacillus* species are likely to be less effective against black pod rot of the pod, because *Phytophthora* has cell walls composed primarily of cellulose. Furthermore, some investigations showed that *B. subtilis* have antagonistic effects against *M. roreri* (Melnick et al., 2011; Falcao et al., 2014). In Colombia, Villamil et al. (2015), in a laboratory trial compared a *Bacillus* strain with two *Trichoderma*, found that one of the fungus strains was more effective and recommended for moniliasis control at the field level.

In the present study, the control of moniliasis, black pod rot and cherelle wilt, only with cultural labors, did not have the expected effectiveness. In Ecuador, in a field trial, the treatments with chemical and biological products had an area of progress of the disease curve, lower than when only diseased pods were removed every 15 days (Estrella & Cedeño, 2012). Perhaps that is why many authors recommend it as a complementary practice to the use of other control methods (Estrella & Cedeño, 2012; Hernández-Gómez et al., 2012; Jaimes & Aranzazu, 2010; Jáuregui, 2001; Ortíz et al., 2015; Tirado et al., 2016, Villamil et al., 2015), because by reducing the inoculum density of the pathogens in the plot, it would help to increase the effectiveness of fungicides in general.

These results demonstrated that, for the control of the pathogens in cacao pods, the cultural labors were important, but when it was complemented with other control methods (biological or chemical), the results were better and allowed to obtein the highest rates of economic return (Jáuregui, 2001). In a similar work carried out in the Ecuadorian town of Puerto Limon, it was found that in a treatment where various components were also combined [Cultural Labor + Chlorothalonil (1 kg ha^{-1}) (every 15 days) + Pyraclostrobin (0.5 kg ha^{-1}) (every 90 days) + Fertilizer (0.4 kg $plant^{-1}$) + Fertilizer (2 kg $plant^{-1}$)], the results showed that it was the one that allowed the highest net income per ha (Anzules et al., 2019). In other study carried out in Manabi (Ecuador), the percentage of healthy pods increased due to the use of chemical fungicides (Arroyave, 2007), but the number of pods and the yield were not directly related and the highest yield of dry cocoa corresponded to T9, a biological control treatment.

Conclusions

In this study, the greatest economic benefit was obtained with the T9 treatment [Cultural labors + Serenade® (0.2 kg ha^{-1}) (every 15 days) + Fertilizer (0.3 kg $plant^{-1}$) + Fertilizer (1 kg $plant^{-1}$)]. For the control of diseases of the cocoa pod, the complement of the cultural labors with other control methods (biological or chemical) were better and allowed to obtain the greatest economic benefits for the producer.

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