Phasing out Highly Hazardous Pesticides in Costa Rica

Project briefing no. 3: Exploring alternatives to HHP fungicides for coffee rust disease *April 2017*

Trials on biological, mineral and chemical alternatives to epoxiconazole

Key points

- Many Costa Rican coffee growers rely on frequent applications of fungicides to prevent coffee rust disease problems. Some of these are HHPs with known or probable chronic health hazards for humans.
- A range of non-HHP alternatives are available, including chemical, biological, botanical and traditional mineral mixtures.
- Results from one season of limited pilot trials in two farms with high and low incidence of coffee rust disease suggest that non-HHP alternatives can deliver good yields.
- All treatments, including synthetic fungicides, failed to control very high disease levels at one farm.
- Yields were not significantly different between treatments even though disease incidence levels varied considerably. Beneficial microorganisms in coffee groves are important for biological control of rust pathogens and for plant health. Results suggest these beneficials may be harmed when control relies on synthetic fungicides.
- For conventional growers, combining one or more non-chemical alternatives with reduced-rate application of non-HHP fungicides is a feasible and affordable option. The mineral plus biofungicide treatments are more suitable for organic farms.

Background

Coffee rust disease, caused by the fungal pathogen *Hemileia vastatrix*, is an important disease of Arabica coffee and in recent years has reached outbreak levels in Central American countries, including Costa Rica, causing severe economic losses for many farmers. Under high infection levels, this disease can badly affect the coffee bush through reduced photosynthesis and early and excessive leaf fall, leading to yield losses, and even death of susceptible bushes.

Coffee rust attack levels and economic damage to coffee groves can be reduced by:

- Careful and timely management of groves, with regular pruning and replacement of old bushes
- Replanting with coffee varieties bred for resistance to coffee rust disease
- Good, balanced nutrition to produce healthy coffee bushes more resilient to attack, with attention to soil and moisture conservation in the groves
- Growing coffee in partly shaded and biodiverse groves, which encourage the many beneficial microorganisms which act as biological control agents of disease
- Well-timed and well-targeted application to coffee foliage of either synthetic fungicides and/or biofungicides and traditional mineral mixtures

In Costa Rica, inappropriate and excessive use of fungicides to try and control the disease has increased coffee growers' production costs and risks the development of fungicide resistance in the coffee leaf rust pathogen. Conventional coffee growers spend considerable money on trying to prevent any yield losses due to coffee rust attack, often spraying fungicides eight times per season. The national coffee research centre CICAFE recommends application of a preventative fungicide when grove monitoring shows incidence of coffee rust up to 10%. At 15% incidence, they recommend spraying systemic fungicides at curative doses. There is no agreed action threshold in relation to disease severity level and individual farms tend to select their own criteria for decision making.

There are some disease-resistant coffee cultivars available in Costa Rica but growers have concerns about the quality of beans produced. Coffee and labour prices influence growers' disease management decisions and when coffee prices fall, many smaller farmers cannot afford the labour for regular pruning or to renew plots.

Hazards and concerns about HHP fungicides

Frequent and high dose spraying of fungicides during the early fruit development period leads to environmental contamination and harm to beneficial and other non-target fauna. Workers usually apply large per hectare spray volumes of fungicides for coffee rust using motorised backpack or tractor-mounted mist-blowers to achieve good coverage over the foliage. It is hard to avoid some degree of operator exposure, especially if proper protective equipment is not used and when spraying above head height. Survey work by the project team has highlighted poor protection practices, especially among smaller scale growers, and few safety precautions taken when mixing or storing spray solutions or washing equipment. Some of the fungicides which Costa Rican growers commonly use to control the disease qualify as HHPs, including epoxiconazole, validamycin A and carbendazim. While none of these are highly acutely toxic to humans, they are classified as chronic health hazards, including probable carcinogens, mutagenic, reproductive toxins or endocrine disruptors (Annex A).

Exploring safer but effective alternatives to HHP fungicides

Two small trials were set up by the project team in 2016 on alternatives to HHP fungicides for control of coffee rust disease: (a) at a conventional farm in El Cántaro in the northern department of Naranjo, and (b) on the National University's experimental farm in Santa Lucía in the central department of Heredia. Groves at El Cántaro site (a), with cultivars Katuai Rojo and Catimor, generally have less coffee rust pressure (low rust incidence of 5-10%), probably due to: good soils; plants well nourished; good shade levels, including use of leguminous shade trees, providing good mulch. The Santa Lucía site (b) has much higher coffee rust incidence (up to 80%), with groves on poorer soils, with few shade trees, no legumes and little soil organic matter.

Different products and combinations were tested, including HHP and non-HHP synthetic fungicides, microbial biofungicides, traditional mineral mixtures for disease control and a plant extract product. The specific products tested were:

- **HHP fungicide epoxiconazole + pyraclostrobin** (Opera ®)
- **Non-HHP fungicide trifloxystrobin + cyproconazole** (Esfera ®)

- **Non-HHP fungicide triadimenol**
- **Mineral mixture sulphur + calcium hydroxide**. A traditional method for treating plant diseases, by disrupting the pathogen's metabolism and growth.
- **Mineral Bordeaux mixture** (copper sulphate + calcium oxide). Another traditional method, reducing disease attack and providing nutrition to the plant.
- **Biofungicide** based on the fungus *Lecanicillium lecanii,* a natural hyper-parasite on the rust fungus. Applied in a formulated product it works as a biocontrol agent.
- **Botanical fungicide**, based on tea tree *Melaleuca alternifolia* oil extract (Timorex ®). Tea tree oil is a known natural systemic fungicide, with preventative and curative properties, which inhibits fungal spore germination and colony growth.
- **Biofungicide/botanical combination**, based on fungi *Beauveria bassiana* and *Nomurea rileyi*, bacterium *Bacillus thuringiensis* + neem tree *Azadirachta indica* oil extract (Roya-OUT ®)

All products are readily available in Costa Rica, except Roya-OUT ®, which is currently being tested by one large coffee estate in Costa Rica. When applying the *Lecanicillium* biofungicide, sodium bicarbonate (baking soda) was included in the spray solution, at the manufacturer's recommendation. It performs a 'cleansing' role to eliminate various fungal spores on the foliage surface, enabling the fungal biocontrol agent to act more directly on the coffee rust pathogen. Spraying was done using a 25 litre motorised backpack at around 468 litres/ha volume, adding a standard adjuvant to each treatment solution to improve adherence to foliage.

The treatment regimes planned for both sites were:

T1= negative control (no fungicides)
T2= HHP fungicide epoxiconazole + pyraclostrobin (Opera ®)
T3= mineral sulfo-calcic mixture, alternated with *Lecanicillium* biofungicide
T4= mineral Bordeaux mixture, alternated with *Lecanicillium* biofungicide
T5= botanical fungicide Timorex in combination with reduced rate non-HHP fungicide trifloxystrobin + cyproconazole (Esfera ®)
T6= biofungicide/botanical combination product Roya-Out ®
T7= non-HHP fungicide trifloxystrobin + cyproconazole (Esfera ®)

Experimental plots were set out in randomised block lay-out, with four replicates of each treatment, with each replicate containing 24 coffee bushes. Assessment was carried out as per CICAFE protocols, by examining two flagged bushes per replicate to measure: coffee rust incidence (% of total leaves with disease lesions per marked branch); disease severity (using a 5 point visual scale of spore-forming lesions); and yield (kg berries harvested per plant). Rust incidence was assessed every month (Mar-Nov.2016) and severity in the last 3 months before harvest (Dec. 2016).

Trial results and treatment costs
Table 1 details the actual sequences and combinations of rust control treatments applied at at El Cántaro trial site. Initial disease incidence was very low (at or below 1%) but when the rainy season began in May, rust incidence and severity steadily increased, reaching the highest levels (up to 32% incidence) in Sept. At this stage the farm owner became alarmed and decided to apply the HHP fungicide (Opera®) in the control and RoyaOut ® treatment

plots. This unplanned intervention therefore needs to be taken into account when interpreting the results.

At the Santa Lucía site initial rust incidence was already very high across all treatments (38-66%) and increased further with onset of the rains, reaching up to 98% incidence and 2.4 out of 5 in severity by Oct. In early Aug it was decided to spray the zero treatment control plot with a cyproconazole fungicide and in Sept. the RoyaOut® treatment was eliminated too, for fear of spreading disease beyond the experimental area. Coffee rust damage reached such high levels by mid Sept. in all plots that the entire trial had to be abandoned, with severe defoliation of some bushes, and no yield data was collected. It should be pointed out that the synthetic fungicide treatments failed to control the disease too or reduce it to acceptable levels.

Table 1. Coffee rust control treatments by date at El Cántaro trial site

Application 1 16/03/2016	Application 2 20/05/2016	Application 3 12/08/2016	Application 4 21/09/2016	Application 5 04/10/2016	Application 6 01/11/2016
1 - Negative control (no fungicide)	No fungicide	Opera	Opera	Opera	No application
2 - Commercial HHP product (Opera = Pyraclostrobin)	Opera	Opera	No application	Opera	No application
3 - Sulphocalcium mixture (sulfur + calcium hydroxide)	*Lecanicillium lecanii*	*Lecanicillium lecanii* + sodium bicarbonate	No application	*Lecanicillium lecanii* + sodium bicarbonate	*Lecanicillium lecanii* + sodium bicarbonate
4 - Bordeaux mixture (copper sulfate + calcium oxide)	*Lecanicillium lecanii*	*Lecanicillium lecanii* + sodium bicarbonate	No application	*Lecanicillium lecanii* + sodium bicarbonate	*Lecanicillium lecanii* + sodium bicarbonate
5 - Timorex (tea tree extract = *Melaleuca alternifolia)* + Esfera = (Trifloxystrobin + Cyproconazole)	Timorex	Timorex	No application	Timorex - Esfera	Timorex
6 - Roya out (*Beauveria bassiana* + *Nomurea rileyi* + *Bacillus thuringiensis* + neem oil = *Azadirachta indica*)	Roya out	Roya out	Opera	Opera	No application
7 - Comercial non HHP product (Esfera = Trifloxystrobin + Cyproconazole)	Esfera	Esfera	No application	Esfera	No application

Table 2 gives the results from El Cántaro in terms of disease incidence and severity. By the final evaluation in Nov. 2016, rust incidence had decreased again from the Sept. peaks, ranging from 3-29% and severity from 1-1.66 out of 5. The treatment with the lowest disease incidence and severity was the non-HHP fungicide (T7), significantly different from the other treatments, with incidence remaining below 7% for the duration and severity under 1.05. Among the treatments containing non-synthetic alternatives, the botanical extract combined with reduced rate non-HHP fungicide (T5) had the lowest disease levels, with incidence under 20% and severity below 1.33.

Although disease incidence and severity varied considerably between treatments at El Cántaro, a different pattern emerged at harvest. Table 3 gives the yield data for the seven treatments at this site, noting also the unplanned substitution with HHP fungicide in the later season for the control and the RoyaOut® plots. Yields did not differ significantly between treatments, with the highest yield obtained with the sulfo-calcic mineral mix alternated with Lecanicillium biofungicide (T3). Neither treatment based solely on synthetic fungicides yielded particularly well, ranking only 4^{th} and 6^{th} for HHP and non-HHP products respectively.

Table 2. Coffee rust incidence and severity at El Cántaro site

Treatment	1st assessment	2nd	3rd	4th	5th	6th	7th		8th		9th	
	20-03-2016	08-04-2016	20-06-2016	20-07-2016	12-08-2016	02-09-2016	21-09-2016		05-10-2016		02-11-2016	
	Incidence (%)	Incidence (%)	Incidence (%)	Incidence (%)	Incidence (%)	Incidence (%)	Incidence (%)	Severity	Incidence (%)	Severity	Incidence (%)	Severity
1.Control	0,86	0,0	0,0	0,0	15	21	24,3	1,1	23,0	1,4	12,8	1,33
2. HHP fungicide	0,0	0,0	0,0	0,0	2*	8*	11*	1,03	10,04	1,1	7,5*	1,12*
3. Mineral s-c + biofungicide	0,72	0,60	0,60	0,58	9	24	26,1	1,13	10,4	1,28	18,5	1,5
4. Mineral B-m + biofungicide	0,0	0,0	2,11	0,0	20	14	32,9	1,25*	18,35	1,38	29,05	1,66
5. Botanical + reduced dose non-HHP fungicide	0,96	0,0	0,68	0,0	19	13	19,5	1,05	12,9	1,19	13,02	1,33
6. Roya-Out	0,99	1,60	0,0	1,55	14	20	25,5	1,07	14,08	1,19	24,5	1,46
7. Non-HHP fungicide	0,50	0,83	0,87	1,57	7*	3*	4,04*	1,02*	0,97*	1,05	3,3*	1*

Table 3. Yield data from El Cántaro site (kg coffee berries picked per bush)

Treatment	**Unscheduled changes to treatment**	**Yield**
T1. Control (untreated)	substituted with 3 applications of HHP fungicide in Aug-Oct	3.14
T2. HHP fungicide		3.06
T3. Sulfo-calcic mix + *L. lecanii* biofungicide		3.39
T4. Bordeaux mix + *L. lecanii* biofungicide		3.02
T5. Botanical fungicide + reduced rate non-HHP fungicide		2.64
T6. Biological + Botanical product Roya-Out	substituted with 2 applications of HHP fungicide in Sep-Oct	3.15
T7. Non-HHP fungicide		2.78

Table 4 itemises the dose rates, frequency of application and costs for the components of the different treatments at El Cántaro site. The treatments based solely on synthetic fungicides were the cheapest, with the HHP fungicide product a little cheaper than the non-HPP option. Amongst the treatments containing non-synthetic alternatives, the cheapest were the mineral mixes alternating with *Lecanicillium* biofungicide, at almost identical cost. The tea tree oil extract Timorex ®, with reduced dose rate of Esfera® fungicide, was the most expensive of all treatments. The cost for Roya-Out® could not be calculated as this product is not marketed in Costa Rica and the price therefore unknown.

Table 4. Treatment dose rates, frequency and costs at El Cántaro site

Treatment and dose rate	No. applications per season	Costs per ha (Costa Rican *colones*)
T2. HHP fungicide (Opera ® at 0.7 l/ha)	3	**59,409**
T3. Mineral s-c + biological (sulfo-calcic mix at 7.6 l/ha + *L.lecanii* biofungicide at 10 l/ha)	sulfo-calcic mix = 1 *L. lecanii* = 4 Sodium bicarbonate 'cleaner' = 3	sulfo-calcic mix = 15, 200 *L. lecanii* = 100,000 Sodium bicarbonate = 800 Total = **116, 000**
T4. Mineral B-mix + biological (Bordeaux mix at 2.3 kg/ha + *L.lecanii* biofungicide at 10 l/ha)	Bordeaux mix = 1 *L. lecanii* = 4 Sodium bicarbonate 'cleaner' = 3	Bordeaux mix = 15,930 *L. lecanii* = 100,000 Sodium bicarbonate = 800 Total = **116,730**
T5. Botanical fungicide + reduced rate non-HHP fungicide (Timorex at 0.86 l/ha) + Esfera at 0.38 l/ha)	Timorex full dose = 3 Timorex half dose = 2 Esfera half dose = 2	Timorex = 222,946 Esfera = 24 Total = **247, 000**
T6. Biological-Botanical product (Roya-Out at 1.5 l/ha + unscheduled HHP fungicide applied late season)	RoyaOut = 2 Opera = 2	RoyaOut = ?? Opera = 42, 435 **Total = ??**
T7. Non-HHP fungicide (Esfera) at 0.75 l/ha)	3	**71, 212**

US$= 543 colones (March 2017)

Discussion points

Replacing HHP fungicides with non-HHP synthetic products appears to be a feasible option, technically and economically. The trifloxystrobin + cyproconazole product produced the best results in terms of coffee rust levels at El Cántaro, under conditions of low disease pressure, and at high disease levels at Santa Lucía it was second best (before the trial was cut short). Its cost is a little higher than the HHP product but the project team consider that it is a viable option for conventional coffee growers.

Among the alternatives, while the botanical extract Timorex ® combined with half dose non-HHP fungicide showed less disease incidence and severity (at both sites), it was very expensive and does not seem a realistic option at the moment.

The lack of any significant difference in yields between the treatments suggests that chemical and non-chemical alternatives to HHP fungicides can work to deliver decent yields. The two treatments combining mineral mixtures with the nationally manufactured *Lecanicillium* biofungicide were the cheapest among non-chemical products and could be a good option for organic growers.

While the unscheduled addition of HHP fungicides to two of the non-chemical treatments probably contributed to the broadly similar yields across all treatments, there is also the question of whether potent synthetic fungicides, with broad-spectrum action against other fungi and microbes, may disrupt beneficial processes in the micro-ecosystem of the coffee foliage. Some fungicides are known to upset the balance between beneficial and harmful fungi and bacteria in coffee groves, aggravating rather than aiding disease control. The project team noticed at El Cántaro that bushes in plots treated with biological products retained far more leaves and with a healthy, green colour than in plots treated with azole fungicides and hypothesise that the fungicides could be negatively affecting leaf retention.

The project survey work and dialogue with conventional, IPM and organic growers has learnt of several good experiences with the tea tree oil extract, enabling users to reduce from four fungicide applications per season to just one or even a half dose. Some organic farms report good results with biofungicides but success with biologicals does mean applying regularly, with up to six sprays. Those who report disappointing results had only applied twice and were in their second season of conversion to organic. The team's understanding is that for biofungicides to work well, background levels of the beneficial fungi need to build up over several seasons. Comparing effectiveness of three applications of synthetic fungicides with three of biofungicides is difficult, as the biologicals work in different ways and take longer to deliver results. A longer term assessment period would be more appropriate.

Project coordinator Fernando Ramírez assesses coffee plant health in trial plots. Credit: IRET.

Conclusions and next steps

It is hard to draw firm conclusions from these limited and partial trials in just one growing season and it was not possible to get clear results in disease control and yields for each planned treatment, due to abandonment of the high disease pressure site and unscheduled fungicide applications insisted on by the farm owner at the low pressure site, compromising results for the control and RoyaOut® treatments. Nevertheless, the results from the commercial farm suggest that good coffee yields can be obtained without needing to rely on HHP fungicides. The failure of even the synthetic fungicides to control high levels of rust at the Santa Lucía site underlines the need for integrated approaches to managing this disease and the risks of relying on chemical methods alone.

The IRET team plan to explore their hypothesis of healthier bush foliage in treatments involving biological products and to conduct further trials with different combinations of biological and mineral alternatives with non-HHP fungicides at reduced dose and frequency in different sites during 2017. More research is needed on how coffee growers can move away from HHP fungicides, phase in safer alternatives and adapt and diversify their groves to encourage beneficial interactions under agroecological principles.

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Annex A Hazard summary of HHP fungicides used on coffee farms in Costa Rica

Epoxiconazole is a broad-spectrum fungicide in the triazole chemical group, with preventative and curative action. It qualifies as an HHP (both under the FAO/WHO proposed hazard criteria and under PAN International's more comprehensive and precautionary HHP criteria), for the hazard criteria summarised below. It can persist in soil and water. While it is not highly toxic to mammals, epoxiconazole is moderately toxic to birds, honeybees, earthworms and most aquatic organisms. It is currently approved in the European Union until 2019. Survey data by this project reveal an average 0.03kg active ingredient used per ha per year in Costa Rican coffee farms.

Carbendazim is a broad-spectrum fungicide in the benzimidazole chemical group, with preventative and curative action. It qualifies as an HHP (both under the FAO/WHO proposed hazard criteria and under PAN International's criteria). It is moderately persistent in soil and can be very persistent in water systems. Carbendazim has a low mammalian toxicity and is moderately toxic to honeybees and most aquatic organisms. It is highly toxic to earthworms but non-toxic to birds. Its approval in the European Union expired in 2014. Survey data reveal an average 0.015kg active ingredient used per ha per year in Costa Rican coffee farms.

Validamycin A is an antibiotic, which also has fungicidal properties and uses. It qualifies as an HHP under PAN International's criteria due to high toxicity to bees. Other hazard data is not readily available. It has never been approved for agricultural uses in the EU. Survey data reveal an average 0.012kg active ingredient used per ha per year in Costa Rican coffee farms.

Hazard classifications which qualify these fungicides as Highly Hazardous Pesticides

Active ingredient	**CAS # ***	**HHP: Acute toxicity to human health classifications**	**HHP: Chronic human health classifications**	**HHP: Environmental concerns**
Epoxiconazole	133855-98-8		**Probable carcinogen**: US EPA 'probable/likely' **Reproductive toxin**: EU/GHS 1A/1B **Endocrine disruptor**: EU EDC 1 or GHS C2 & R2	
Carbendazim	10605-21-7		**Mutagenic:** EU/GHS 1A/1B **Reproductive toxin**: EU/GHS 1A/1B	
Validamycin A	37248-47-8			Highly toxic to bees: US EPA

**CAS # = Chemical Abstracts Service unique identifying code for individual chemicals*