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***Serratia*, Mi Encanto: How Biological Control Agents Can Mitigate Colombia's *P. cinnamomi* Crisis**

In Disney's new film *Encanto*, Colombian singer Carlos Vives describes Colombia as a paradise. "Todos llegan para gozar," he sings—everyone comes to enjoy Colombia's bounty (Vives 0:15–18). Despite its relative prosperity as an upper middle-income country, however, Colombia's development has been lopsided. Its income distribution is heavily weighted towards the top-earning 10% of the population, who, as of 2019, hold 40.3% of the country's wealth—leaving 42.5% of the population beneath the poverty line and 15.1% of the population in extreme poverty (Adriaan, "Poverty and inequality"). Most of this poverty is concentrated in Colombia's rural districts, whose populations mainly comprise small subsistence farmers. This places Colombia at seventh in the world for income inequality (World Food Programme, "Colombia").

The two diets prevalent in Colombia are one of fruit-vegetable/dairy reliance (including heavy milk, cheese, raw and cooked vegetable, whole and juiced fruit, beef, and chicken consumption) and traditional/starch reliance (including sugar, rice, bean, tuber, banana, beef, and coffee consumption) (Quintero-Lesmes and Herran, Pabón et al.). The average Colombian family has a household size of 4.53 people, with a large proportion of the population in possession of commodities like a flush toilet (86.6%), TV (91.2%), and cellphones (90.5%). However, these numbers vary significantly, and rural areas, which are primarily populated by Indigenous and Afro-Colombian populations, suffer the most.

In order to understand why these areas of Colombia are in such severe straits, it is helpful to understand Colombia's history. Since its emergence as a republic in 1886 after a tumultuous succession of regimes, Colombia has been systematically ravaged by periods of civil warfare. The first period, La Guerra de Los Mil Días, wherein 120,000 people died, was rooted in turmoil between the Partido Conservador Colombiano and the Partido Liberal; and, only fifty years later—in 1948—another period of warfare caused by rifts between the parties took hold of the country, this time in the form of a ten-year war that killed 300,000 people. This period, termed La Violencia, culminated in the formation of the National Front, where both parties agreed to alternate positions of power, a pact that lasted until 1974. While the Front put an end to the war, it was also the impetus for Colombia's history with guerrilla warfare and drug trafficking. As socioeconomic and political problems continued to develop in the 1960s, left-wing extremist groups began to form, including the Fuerzas Armadas Revolucionarias de Colombia, commonly known by their acronym FARC. By the late 1990s, drug production—the guerrilla's primary means of financial support—and unemployment were running high. This led to the emergence of far-right paramilitary groups—like the Autodefensas Unidas de Colombia (AUC)—whose mission was to combat the guerrilleros by any means possible, including by terrorizing citizens suspected to be allied with them (Federal Research Division, "Country Profile: Colombia").

Although the violence was widespread, it concentrated itself in rural areas. One such area were the Montes de María, which lie on Colombia's Caribbean Coast. The Montes are one of the most vibrant epicenters for biodiversity in Colombia—itsself the second-most biodiverse country in the world—but, up until the early 2000s, they were an epicenter for guerrilla warfare, too. The turmoil left lasting scars in their social fabric, even after the AUC was dissolved in 2006 and the FARC signed a ceasefire treaty in 2017. "[We] lived in a period of fear, of loneliness," said a resident of Pichilín, one of the smallest villages in the Montes. "A car would come into the town and we would run" (Phenecie). But isolation and paranoia were not the only blights brought by the conflict. In the late 2010s, avocado farmers began to

notice a strange phenomenon. The fruits of their avocado trees began rotting at the stems; tree crowns began to thin as leaves wilted and discolored. When leaf fall finally came, the avocados were small, hard, and—most problematically for the farmers—impossible to sell (Serrazina).

The culprit is *Phytophthora cinnamomi*, “one of the most devastating plant pathogens known” according to a 2018 study (Hardham and Blackman). *P. cinnamomi* is an oomycete, a fungus-like organism that breaks down organic matter. Like many oomycetes, *P. cinnamomi* can lie dormant within an infected plant, and it is this, as well as its adaptability to different environments, that makes it so dangerous. *P. cinnamomi*'s chlamydospores can survive up to six years without nutrients, allowing the pathogen to spread stealthily over an extended period of time. When a chlamydospore is finally exposed a certain combination of amino acids and root-originated compounds, it germinates to produce sporangia, which in turn make zoospores that enter and colonize plants by breaking through non-woody tissue. This causes widespread tissue rot. The pathogen then emits toxins that stop water flow, leading to leaf necrosis (Reuter). *P. cinnamomi*'s devastating effects make it a well-known danger in the United States, Europe, and Australia (IUCN), but in El Carmen de Bolívar, the largest town in the Montes de María, it is an entirely new kind of killer.

The origins of *P. cinnamomi* in the Montes are still nebulous. Its presence only became notable shortly after the conflict, during which the Montes were alive with activity; some have speculated that one of the many armed groups passing through spread the pathogen to the area, especially since the movement of people and their associated livestock, vehicles, and gear is correlated with a higher chance of pathogen spread (Francl). Whatever the cause, the lack of agricultural management caused by widespread displacement meant that farmers couldn't see the initial signs of the infection until it was too late to stop the spread (Morgan).

In previous cases, South American farmers have attempted to stave off *P. cinnamomi* using integrated disease management methods. However, these methods—which include strategies such as adding potassium silicate to soil and spraying plants with pesticides—are designed for large-scale farming operations (Ramírez-Gil). Not only could they be potentially harmful to other ecosystems in the Montes area, they are impractical and expensive to implement on a small scale. A holistic approach—one appropriate for small farms—would be more effective for the farmers in the Montes. However, these kinds of approaches are not nearly as immediate or successful. And that's a problem.

After decades of conflict, Colombia's economy has been severely damaged. The recent influx of Venezuelan refugees—a mostly jobless and resource-depleted population—has only aggravated Colombia's economic plight (ElDiario, “Los efectos económicos de la migración venezolana en Colombia”). And, when the pandemic hit, Colombia implemented strict lockdown procedures—but with a population that mostly deals in in-person employment and cash payments, thousands were put into severe financial straits. Conflict—this time spurred by civilians—is threatening to break out again (CNN Español, “Cronología de las protestas de 2021 en Colombia.”). All of this means that the Colombian government is eager for an economic boost, one which could easily be provided by more large-scale farming operations, which usually grow cane sugar, coffee, or oil palm monocultures. The small-holder farmers of the Montes, a region famous for its fertility, are already under pressure to turn their land over to large-scale farming operations, but the Colombian government will sooner seize their land for companies that can afford integrated disease management methods than invest resources in solutions for small-scale farmers.

The consequences of losing Colombia's subsistence agriculture communities could be severe, however. As large-scale farming operations push small farmers to urban areas, the economic recovery Colombia is undergoing could take a significant blow. In the countryside, farmers have the freedom to set their own rates, giving them a modicum of control over their income; when they move to cities, however, they are outpriced by urban sellers. This means that many displaced families end up unemployed or with irregular employment, exacerbating poverty, malnutrition, and housing issues already prevalent in Colombia's low-income urban areas (Atehortúa Arredondo et al., "The Effects of Internal Displacement on Host Communities").

One method of control being hailed in agricultural circles is phosphite treatment, which may be the new edge of eco-friendly fungicides. In order to treat infected plants, phosphites are usually applied through bark injections, although spraying, high-pressure injections, capsular implants, and soil drenches are also viable (Hunter, Wilkinson et al.). Once applied, phosphites accumulate in the phloem, where they are transported through the xylem and accumulate in the root system (Hardy et al.). The effects on *P. cinnamomi* infestations are dramatic. In the mycelium, hyphal walls lyse and become otherwise distorted, leading to stunted hyphal nodes (King et al.). These growth defects slow the spread of the pathogen. Likewise, *in planta* applications of phosphites to soil slow the growth of both zoospores and sporangia, although both of these were still being produced (Wilkinson et al.). While imperfect, phosphite treatments may be a more cost-effective alternate to the usual pesticides used to control *P. cinnamomi* infections. While some phosphite treatments, such as spraying, need to be repeated across a 4 – 6 week period (Hardy et al.), injections are single-use and may therefore be cheaper for farmers (Wilkinson et al.); the same cannot be said for common chemical treatments for *P. cinnamomi*, which include focetyl-Al, phosphate, something.

However, the agricultural and environmental costs of phosphite treatments are not negligible. While phosphites have low phytotoxicity, phosphite applications significantly increase phytotoxicity in plant tissue over the 36 kg/ha⁻¹ threshold—the usual application rate is 24 kg/ha⁻¹. This increase in phytotoxicity brings with it leaf death, defoliation, chlorosis, and growth defects; among those defects, foliage rosetting and abnormally small leaves. The same 36 kg/ha⁻¹ threshold also had detrimental effects on the fertility and sexual health of plants in a variety of families; while *Persea* species were not affected, phosphite runoff could affect the surrounding forest ecosystem in the Montes more than anticipated. Currently, vesicular-arbuscular mycorrhizal fungi in areas where phosphite treatments are in use have been noted to increase up to four times in production. Changes of this kind to ecosystems—whether they lead to the decrease or increase of a species presence—may severely destabilize local ecosystems.

The ramifications of runoff in the Montes could be severe; if the pathogen were to extend its borders for only a few more miles, it could wreak havoc on Colombia's forests. The Montes are home to no less than three protected forest areas, one being the Los Colorados sanctuary. Besides being an International Union for Conservation of Nature (otherwise known as IUCN) protected area, Los Colorados is home to over 208 species of birds and forty-four species of mammals, among which is the endangered gray-bellied monkey. All those species, however, depend on the flora of Los Colorados, to which the appearance of *P. cinnamomi* would be a death sentence.

One method, however, could save the future of Colombia's small farming communities without encountering the challenges posed by runoff. Biological control agents, or BCAs, are a developing frontier in agriculture, and are being used to mitigate pests, boost plant growth, and strengthen environmental tolerance. Traditionally, biological control methods have entailed pitting natural enemies against each other: if an area were to become infested by invasive mice, a biological control method would dictate sending in a natural enemy—like hawks or snakes—to cut back the invasive population. This kind of biological control has its critics; species released to mitigate invasive groups often become invasive themselves, precipitating a hellish cycle of initial control and subsequent loss of it. Recently,

however, biocontrol has extended to strains of microorganisms and GMOs. It is this kind of BCA that could be the key to stopping *P. cinnamomi*.

In a 2020 study published in the *Journal of Integrative Agriculture*, a group of researchers led by David Granada found that a strain of *Serratia* bacteria could be used to combat *P. cinnamomi* root rot. The strain was selected from “indigenous antagonistic isolates”—antagonistic here meaning anti-oomycetic—found in avocado trees from the region of Antioquia. (It is worth noting that while some indigenous avocado varieties have shown resistance to *P. cinnamomi*, Colombia’s position as an international monolith of avocado production prevents it from straying too far from the known commercial varieties.) Granada and his team watered infected seedlings with a water/oil emulsion containing *Serratia*, distilled water, palm oil, and traces of other compounds. What they found could be groundbreaking: the *Serratia* strain was so effective in combating the infection that, when Granada and his team re-examined the seedlings only ten days later, there were no traces of *P. cinnamomi* left: not only had the strain halted the infection, it had completely eliminated it (Granada et al.).

The ready availability of a *Serratia* emulsion similar to the one mixed in the study could be a lifesaver to the farmers of the Montes, especially since it would combat the most economically damaging effect of *P. cinnamomi* infections—plant death. It has its limitations: part of the problem with BCAs is that strains react differently in certain climates or ecosystems; *Serratia* may not be as effective in the Montes as it is in Antioquia. If the strain fails, if it is inaccessible, or if it is unaffordable, the Colombian government, desperate to regain economic footing after decades of internal conflict, will look away as their land is turned to cash-crop fields. But, as one farmer in the Montes put it, “Agriculture is not assured.” Should the *Serratia* emulsion succeed, rural farmers—both in Colombia and across the world—will be able to put food on their tables for decades to come.

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