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Why the coffee berry borer *Hypothenemus hampei* Ferrari (Coleoptera: Curculionidae) is a destructive plague?[ϕ]

Valentina García-Méndez[1], Victor Manuel Almaraz-Valle[2*]

Introduction

In México and worldwide, coffee is among the most important crops; however, its production faces multiple challenges and threats (Barrera and Gomez 2019). Factors, such as low bean prices, high production costs, and climate change affect their yields. Among the most pressing issues for the coffee growers are the plagues and diseases that can drastically reduce both the quality and quantity of the harvest (SENASICA 2019).

In Mexico and globally, one of the most important threats to coffee crops is the berry borer *Hypothenemus hampei* Ferrari (Coleoptera: Curculionidae), which is a small beetle that feeds on coffee beans and is the most destructive plague for this crop (Fig. 1) (CropLife Latin America n.d.; SENASICA 2019). If this beetle is out of control, it can cause significant losses over $500 million USD annually to global coffee production (USDA 2004). Although this beetle was first detected in Mexico in 1978 in the Soconusco region of Chiapas, it has now spread to nearly all coffee-growing regions in the country (Bustillo 2006).

In Mexico, this beetle affects approximately 800,000 ha of coffee in areas between 600 and 2,200 m above sea level, with temperatures ranging from 19 to 21 °C (Constantino *et al.* 2011). The objective of this work is to describe and analyze the impact of the coffee berry

[ϕ] Universidad Autónoma de Chiapas, Licenciatura en Caficultura. Carretera Jaltenango a Francisco I. Madero Km. 2.6 s/n, Ángel Albino Corzo, Chiapas, México C.P. 30370. https://orcid.org/0009-0004-5265-4265, [2] Colegio de Postgraduados, Posgrado en Fitosanidad-Entomología y Acarología, Campus Montecillo. Carretera México-Texcoco Km. 36.5, Montecillo, Texcoco 56264, Estado de México. https://orcid.org/0000-0002-3673-8002, *Corresponding author: almaraz.victor@colpos.mx
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borer on coffee crops, exploring its biology, reproductive mechanisms (including its interaction with bacteria genus *Wolbachia*), its geographic spread, and the challenges it poses for field management and control to raise awareness about its economic and plant health importance.

Figure 1. Coffee bean bored by the coffee berry borer *Hypothenemus hampei*.

Plagues and diseases in coffee crops: a silent threat

Worldwide, coffee crops are exposed to various plagues and diseases that can reduce production by up to 50 % (Bustillo 2006). In Mexico, coffee crops are attacked by at least 27 insect species and two mite species, including the coffee berry borer *H. hampei*, the leaf miner *Leucoptera coffeella*, the green scale *Coccus viridis*, the red mite *Oligonychus yothersi*, and the black aphid *Toxoptera aurantii*. All these cause severe reductions in yield and quality of the coffee. Additionally, around 12 microorganisms—mainly fungi and nematodes—threaten the coffee health, such as the coffee leaf rust *Hemileia vastatrix*, the American leaf spot or "ojo de gallo" *Mycena citricolor*, the anthracnose *Colletotrichum kahawae*, the Fusarium wilt *Fusarium oxysporum*, and the root damage caused by nematodes like *Meloidogyne* spp. and *Pratylenchus* spp. (Bustillo 2006; SENASICA 2019; CropLife Latin America n.d.).

Among all threats, the coffee berry borer causes the most serious damage since it feeds exclusively on coffee beans (Fig. 2), reduces the quality and increases the production costs due to the need for detailed control measures (SENASICA 2019; Barrera and Gomez 2019).

Figure 2. Coffee berry borer *Hypothenemus hampei* feeding on a coffee berry.

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Origin and spread

The first report of this beetle as plague of coffee crops was in Gabon, Africa, in 1901 (Franqui and Medina 2003). In fact, this beetle is native to equatorial Africa, where it naturally coexists with coffee plants under the canopy of tropical rainforest trees (Bustillo 2007). In the wild, the beetle is not a phytosanitary issue because their ecological balance is controlled by nature.

As coffee crops expanded globally the beetle became an invasive plague affecting more than 60 countries now. In the Americas, it affects crops in Brazil, Colombia, Costa Rica, Mexico, Nicaragua, Peru, and Venezuela (CropLife Latin America n.d.).

How did the coffee borer enter Mexico?

The beetle spread has been consistent worldwide. In 1918 it was first detected in Sumatra and Brazil, and in 1971 was found on a farm in Chicacao, Suchitepéquez, Guatemala (Franqui and Medina 2003). Since then, it spread through Central America and reached Mexico in 1978, most likely introduced via infested coffee berries and other contaminated plant materials transported from Guatemala to the Soconusco region of Chiapas (Olvera *et al.* 2020; Franqui and Medina 2003).

The beetle was first detected in a wet coffee processing facility near the Mixcum ejido and later found in nearby coffee plantations in Cacahoatán, Chiapas. Since then, it has rapidly expanded to almost all coffee-producing regions in Mexico affecting thousands of coffee growers. In economic terms, if this beetle is left uncontrolled it can cause global losses estimated at over 500 million USD annually with significant reductions in yield and quality that severely impact the income of smallholder farmers (Johnson and Manoukis 2021; García-Méndez *et al.* 2023). By 2006, the beetle was considered a plague in 13 states of Mexico affecting more than 384,000 ha of coffee crops (SENASICA 2019; Olvera *et al.* 2020).

How does this beetle affect coffee crops?

The beetle is tiny but has an enormous damaging impact because it feeds and reproduces inside the coffee bean where it carves boring tunnels (galleries), which in turn degrade the coffee's commercial quality (Fig. 3). Consequently, these tunnels promote the spread of opportunistic microorganisms, which accelerate the bean decomposition (Fig. 4) (Franqui and Medina 2003; Constantino *et al.* 2011).

Worldwide, coffee-importing countries completely reject bored-damaged beans due to quality standards, which negatively impacts the coffee exports and economically harms the coffee growers. Farmers may lose up to 20% of their crop and see prices drop by 30–40 % with 5–78 % of berries being damaged in heavily infested areas (USDA 2004; Johnson and Manoukis 2021).

Figure 3. Coffee borer *Hypothenemus hampei* drilling into the basal part of the coffee fruit.

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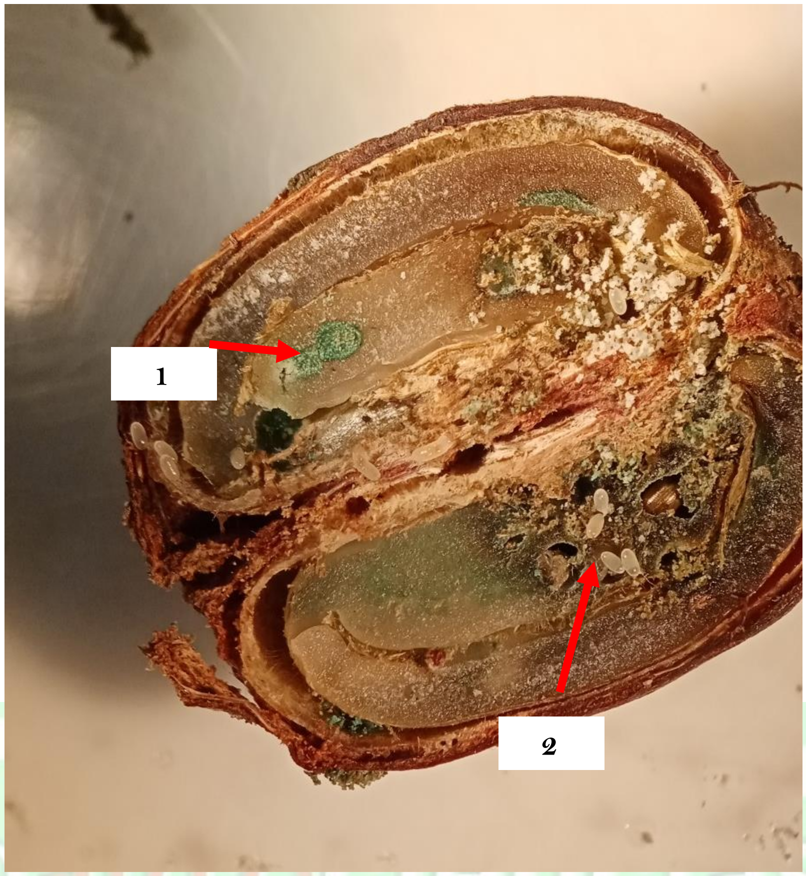

Figure 4. 1) Coffee bean damaged showing proliferation of opportunistic organisms. 2) Coffee borer eggs laid on the bean.

Biology and colonization

The beetle has a well-adapted life cycle in coffee plantations. Here, the adult female bores the coffee bean and lays her eggs (Fig. 4). After hatching, the larvae feed on the endosperm, which in turn degrades the bean's quality. Once matured, males mate with their sisters before dying and new females emerge to find and infest other berries (Barrera *et al.* 2006).

The beetle reproduces by haplodiploidy, as females have two copies of their genetic material and males have only one and are genetically simpler (Benavides 2008; Constantino *et al.* 2011). Interestingly, most offspring inherit only their mother's DNA, which makes them nearly clones. In this scenario, a female produces identical daughters without significant genetic input from males, and this process enables a rapid population growth and a widespread colonization of the beetles in the coffee beans (Bustillo 2008; Constantino *et al.* 2011).

To better understand this genetic process, it is like a family where all daughters look like their mother and the few males have limited roles and cannot pass on their genes to the offsprings. This reproductive system causes the beetle to attain a population growth hard to control since a single female can produce a substantial number of offspring with little male involvement (Bustillo 2006; Benavides 2008).

Wolbachia genus and sex in the berry borer beetle *H. hampei*

Wolbachia is a genus of bacteria closely linked to the reproduction of the beetle (Mariño *et al.* 2017). Since females transmit most of their genetic material to the offspring, this favors a rapid population growth. *Wolbachia*, which lives inside some insects, can further influence this process by altering the sex of the offspring, increasing the number of females and thus accelerating the plague spread in crops (Benavides 2008; Mariño *et al.* 2017).

Wolbachia produces a male feminization—turning genetically male beetles into functional females. This process increases the proportion of females, which are responsible for infesting new coffee beans. Additionally, *Wolbachia* can cause reproductive incompatibility, where infected males cannot reproduce with uninfected females. However, if infected females reproduce, they pass *Wolbachia* to all offspring and consequently accelerate the plague population growth in the coffee crop (Benavides 2008).

If the beetle has by *de facto* an efficient reproductive system, *Wolbachia* may enhance its expansion by ensuring more females for each generation—helping explain the rapid establishment of the beetle plague in new geographic regions (Mariño *et al.* 2017).

Reproductive diapause and mass emergence

When conditions are unfavorable, the beetle enters a reproductive diapause—a hibernation-like state. During this period, the metabolism slows, and females gather inside dried coffee beans to conserve energy and moisture. This moment allows them to survive the offseason, and they appear in masses when new coffee berries develop.

Diapause has an additional management challenge as it enables the beetle plague to persist in post-harvest fields, especially where unharvested coffee beans are left behind (Barrera *et al.* 2006).

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Control measures

The coffee berry borer can be controlled using a mix of cultural, biological, chemical, and genetic strategies. Combining these approaches is the best way to get good results. New coffee plant varieties, that naturally resist beetles, are being developed and they could reduce infestations by up to 73 % (Molina *et al.* 2022). However, regularly checking the fields with traps is still essential to know exactly when to act (García-Méndez *et al.* 2023).

Cultural practices are the foundation for better beetle population control. These include frequent pruning and collecting fallen coffee fruits, so the insect has nowhere to hide or reproduce. By doing this well it can reduce infestations by 50 % to 80 % (Aristizábal *et al.* 2016; Moreno-Ramirez *et al.* 2024). Also, managing shade and keeping a balanced microclimate on the farm helps slow down the beetle's growth (García-Méndez *et al.* 2023).

Another natural option is using fungi, like *Beauveria bassiana*, which infects and kills the insect with an effectiveness of up to 70 % (Aristizábal *et al.* 2017; Moreno-Ramirez *et al.* 2024). There are also small wasps, like *Phymastichus coffea*, that attack the beetle and can reduce its numbers by up to 50 % (Molina *et al.* 2022). Chemical insecticides can be effective (up to 88 % reduction), but only if they are used at the right time when the female beetle is flying and most vulnerable (García-Méndez *et al.* 2023; Moreno-Ramirez *et al.* 2024).

Conclusion

Every day you enjoy a morning coffee, or even during a good conversation, it's hard to imagine the struggles little coffee beans endure to reach your cup. But, behind the aroma and flavor lies an ongoing battle against a tiny, yet powerful enemy: the coffee berry borer beetle. This beetle doesn't just bore coffee beans—it leaves behind vast economic losses and multiple headaches for coffee growers who must work very hard to protect their coffee crops. Like a movie villain, the beetle has a nearly indestructible reproductive strategy by rapidly multiplying with minimal male involvement and even being helped by *Wolbachia*, a bacterium that seems to side with it by boosting female numbers and plague spread. If the coffee borers were a soccer team, nature gave them every advantage. The team plays with more strikers (females infesting new fruits), has the best "bacterial coach" (*Wolbachia*) tweaking the rules to allow more players to be on the field, and when conditions get tough, instead of quitting, the team remains in defensive mode (diapause) until it can strike again. So, next time you sip your coffee remember what it takes to produce it—and the efforts made to protect the bean quality. And if you ever wonder why coffee can be expensive, think of this tiny but clever beetle that, despite being just a few millimeters long, gives coffee growers across the world a serious headache.

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