Topics in

Agricultural Entomology XIII

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PREFACE

The Graduate Program in Agronomy (Agricultural Entomology) at the UNESP Faculty of Agricultural and Veterinary Sciences in Jaboticabal has always been characterized by its focus on Integrated Pest Management (IPM). Since its foundation, the program has graduated 287 students with a master's degree and 148 Ph.D. students. They are now active in various areas of the public or private sector and contribute to agriculture's economic and environmental sustainability.

This e-book entitled "Topics in Agricultural Entomology - XIII" was made possible through the immense effort of the Organizing Committee, formed by MSc and Ph.D. students from all research areas of our Graduate Program. In its 14 chapters, readers will find information on the most diverse areas of IPM, with a richness of information on both the fundamental and applied aspects of IPM.

As coordinator of the 2022 edition of the Winter Workshop on Agricultural Entomology, it is my pleasure to provide event attendees with an e-book of excellent content, demonstrating the importance of our research to society.

Prof. Ricardo Antônio Polanczyk

FCAV/UNESP

PPG Entomologia Agrícola Coordinator

SUMÁRIO

CAPÍTULO 10

INTEGRATED MANAGEMENT STRATEGIES FOR KEY PESTS OF COFFEE CROP

Bruno Henrique Sardinha de Souza

1 I INTRODUCTION

Brazil is the largest coffee producer and exporter worldwide. In the 2022 crop season, coffee production was estimated at more than 55 million 60-kg bags, for both *Coffea arabica* and *C. canephora* species; of this amount, almost half comes from crops grown in the state of Minas Gerais (CONAB, 2022). Despite Brazil's prominence in the coffee production international scenario, losses due to insect pests represent one of the main problems both in quantitative and qualitative terms. Among the main coffee-growing regions in the country, coffee leaf miner and coffee berry borer stand out as key pests.

2 I KEY COFFEE PESTS: COFFEE LEAF MINER AND COFFEE BERRY BORER

Coffee leaf miner, *Leucoptera coffeella* (Lepidoptera: Lyonetiidae), is the main insect pest of coffee plants in Brazil due to its widespread occurrence in producing regions, causing significant economic losses, especially in the Cerrado areas of Minas Gerais state (Mendonça et al., 2016). Coffee leaf miner damage to coffee crop is due to photosynthetic area losses by larvae feeding in the leaf mesophyll tissue, creating mines and galleries as distinctive injury. Under severe infestations, pest attack can lead to premature leaf fall, further impacting photosynthesis and hence plant yield. In regions favorable to coffee leaf miner infestations, such as under environmental conditions of high temperature and low relative humidity, and where crop cultivation is carried out mechanically and with larger row spacing, high population densities may occur, decreasing up to 80% coffee production in the following crop season (Souza et al., 1998).

Coffee berry borer, *Hypothenemus hampei* (Coleoptera: Curculionidae: Scolytinae), is another key pest of coffee plantations. It is regarded as the second most important pest in arabica coffee (*C. arabica*) and the main pest in robusta coffee (*C. canephora*) in Brazil. In global terms, the coffee berry borer stands out as the main pest of the crop and is currently present in nearly all countries, but Nepal and Papua New Guinea (CABI, 2022).

Coffee berry borer infestations in coffee plantations start about 90 days after the main flowering in green berries, which is characterized as its transit or flight period. Females penetrate the berry by boring a hole in the disk region until reaching the seed. Under ideal humidity conditions in the fruit (40-60%), females lay eggs in the galleries formed by their feeding, with larvae completing development in the endosperm. These injuries can lead to premature fruit abscission, in addition to quantitative damage by grain weight losses and qualitative damage to coffee beverage characteristics (Souza et al., 2014).

3 | CONTROL METHODS USED FOR KEY COFFEE PESTS

Key pests of coffee plantations, *L. coffeella* and *H. hampei*, are mainly controlled by chemical insecticide products. Applied insecticides belong to various chemical groups and have different mechanisms of action. In the case of coffee leaf miners, insecticides are applied both by spraying and via drench, while for coffee berry borer by only spraying. About 150 commercial products are currently registered for coffee leaf miner control, including several active ingredients belonging to organophosphates, carbamates, pyrethroids, neonicotinoids, spinosyns, butenolides, diamides, benzoylphenyl-ureas, avermectins, and juvenoids groups. Commercial mixtures between some of these insecticides or even between insecticides and fungicides are also available. In addition to insecticides, a sex pheromone-based product is also registered for use in delta traps for insect population monitoring (MAPA, 2022).

On the other hand, few insecticides are officially registered for coffee berry borer, totaling 29 commercial products, in addition to another 15 products based on *Beauveria bassiana* and one more kairomone (methanol: ethanol) used for monitoring using specific traps for coffee berry borer. Of the 29 chemical insecticides registered, 14 are based on the organophosphate chlorpyrifos, representing almost half of the products. Insecticides of the chemical groups of diamides, metaflumizone, spinosyns, oxadiazines, avermectins, and pyrethroids, formulated singly or in commercial mixtures, complete the list (MAPA, 2022).

The use of insecticides is complemented by cultural practices, such as thorough fruit-harvesting in plants followed by reharvesting and sweeping of fruits remaining on the ground, which are the main foci of pest infestations (Silva et al., 2010). For coffee leaf miner, the resistant cultivar ‘Siriema AS1’ was developed, which is a hybrid originated from a cross between *C. arabica* x *C. racemosa* (Carvalho et al., 2013; Matiello et al., 2015). However, more work needs to be done under high insect infestation to confirm the efficiency of the host plant resistance. Green lacewings have also been used by some farmers, whose larvae are predators of coffee leaf miner larvae.

Due to the high cost of the modern insecticides, frequent use of highly toxic insecticide chemical groups, and pest resistance to some active ingredients, currently, few are the options available for the management of these two key pests of coffee plantations. Thus, research aimed at developing strategies and applying efficient and sustainable technologies in practice for their integrated management should be encouraged.

4 I INTEGRATED PEST MANAGEMENT

The occurrence of high coffee leaf miner and coffee berry borer population densities in the main coffee-growing regions of Brazil and the potential cases of resistance to active ingredients of the most used insecticides make inefficient the use of only one control method, such as only insecticide applications. There are reports, for example, that coffee leaf miner populations resistant to chlorantraniliprole in areas of intense coffee production can reach 85%, being up to 94% in Bahia state, with resistance levels ranging from 10 to 40-fold (Leite et al., 2020). Several cases of resistance in *L. coffeella* populations to organophosphates were also identified (Fragoso et al., 2002; 2003), which is one of the most used insecticide groups in coffee crop.

Integrated Pest Management (IPM) programs should be developed and implemented mainly at regional scale to increase pest control efficiency, as well as to reduce production costs and toxic residues in agroecosystems and final produce. IPM is a planning and monitoring system for strategic deployment of pest control tactics, keeping insect pest populations below economic injury levels, while maintaining productivity and quality of agricultural produce, in which pest control decision-making is based on cost-benefit analysis based on economic, ecological, toxicological, and social principles. IPM has a multidisciplinary approach, involving several areas of knowledge such as Entomology, Plant Physiology, Ecology, Plant Nutrition, Chemistry, Statistics, Toxicology, and Economics, among others (Souza, 2020).

IPM programs for key coffee pests should be always optimized to reduce damage, benefiting both commodity coffee yield and specialty coffee production and quality. The Laboratory of Plant Resistance and Integrated Pest Management (LARP-MIP) at the Federal University of Lavras (UFLA) has conducted several studies to develop efficient and sustainable strategies for IPM-Coffee. Research has achieved promising results in terms of coffee leaf miner and coffee berry borer population reductions. The studies are performed by undergraduate students in Agronomy and Master's and PhD students in Entomology. The results are published in monographs, dissertations, theses, and scientific and extension publications. In the next section, the main results of these studies on integrated management strategies of coffee leaf miner and coffee berry borer are summarized.

5 I INTEGRATED MANAGEMENT STRATEGIES OF COFFEE LEAF MINER AND COFFEE BERRY BORER

Plant Resistance is one of the cornerstones of IPM and consists of growing cultivars or hybrids of plants with chemical and morphological traits that defend them against insect pest oviposition, feeding, and development. Plants can express these defense mechanisms constitutively or induced, i.e., when manifested constantly or only after a pest attack, respectively. They can also be direct when these plant traits directly affect insect biological performance, or indirect, by producing volatile organic compounds or extrafloral nectaries that attract natural enemies, favoring both plant growth for acting as biological control agents and pest population reductions (Smith; Clement, 2012).

Of all Brazilian coffee plantations, 90% are grown with IAC Mundo Novo and IAC Catuaí cultivars (Giomo, 2015; Gomes; Galdino, 2017). There is a lack of information on resistance levels to key pests in commercial cultivars available on the marketplace. This contributes to delaying transfer of knowledge to coffee growers, who end up not cultivating the modern cultivars. Therefore, more research under field and laboratory conditions is needed to assess the resistance levels in commercial cultivars, characterize the resistance types, and identify chemical and morphological mechanisms involved.

Coffee cultivars have been developed using classical and molecular breeding techniques, mainly by public research institutions (Guerreiro Filho, 2006). Fundação Procafé launched the cv. Siriema AS1, a hybrid from a cross between *Coffea arabica* (cv. Mundo Novo) x *C. racemosa*. This cultivar possess resistance to coffee leaf miners and coffee leaf rust, and is the only cultivar recognized as resistant to the insect pest (Carvalho et al., 2013). For coffee berry borer, little is known about resistant cultivars, with resistant germplasm only being identified in non-commercial *Coffea* species (Sera et al., 2010). In recent years, studies have evaluated the categories and levels of resistance to coffee leaf miner and coffee berry borer, and the main results will be presented herein.

In Lavras, southern Minas Gerais, *L. coffeella* infestation was evaluated monthly over three consecutive crop seasons. The study investigated the resistance in 30 coffee genotypes, of which 28 are commercial cultivars. Temperature and rainfall monthly averages were also recorded to correlate these abiotic factors to coffee leaf miner population fluctuations. When comparing the resistant cultivar Siriema with the susceptible Catuaí Vermelho IAC 144, for example, coffee leaf miner infestation was much more reduced by the resistant genotype in almost the entire evaluation period, with accentuated differences in months of higher population peaks (from August to November). Therefore, cv. Siriema has moderate resistance to *L. coffeella* in the field and can serve as an important control tactic in IPM. Rainfall was also an important factor in regulating coffee leaf miner populations, which can help in terms of optimizing the period of pest sampling control decision-making (Figure 1).

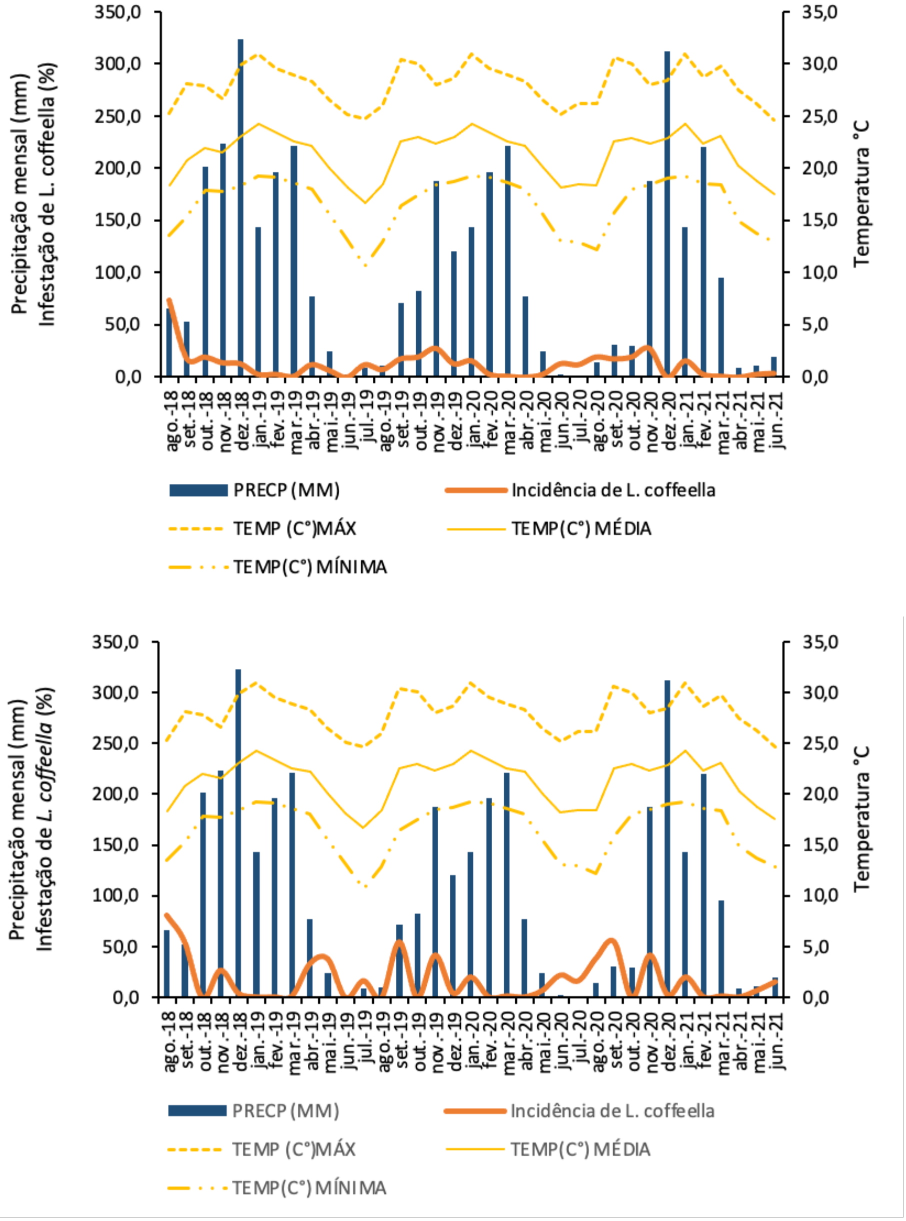

Figure 1. Mean percentages of leaves mined by coffee leaf miner in resistant (Siriema - A) and susceptible (Catuaí Vermelho IAC 144 - B) cultivars and mean monthly temperature and rainfall over three years of evaluation in Lavras, MG (Brazil).

Oviposition preference assay with *L. coffeella* was also carried out in the laboratory using a free-choice approach, comparing cv. Siriema progenies and the commercial cultivar Arara, and characterizing the types and levels of resistance. Most dual-choice comparisons showed a higher number of eggs in the cv. Siriema progenies than in cv. Arara, ruling out the presence of antixenosis-resistance (Table 1).

Genotype	Eggs/cm^2 (Siriema)		Eggs/cm^2 (Arara)		*P*-value
T70	0.21 ± 0.05	a	0.19 ± 0.04	a	0.758
T71	0.22 ± 0.04	a	0.08 ± 0.01	b	0.004
T72	0.19 ± 0.04	a	0.07 ± 0.02	b	0.024
T73	0.27 ± 0.05	a	0.13 ± 0.03	b	0.040
T66	0.13 ± 0.01	a	0.13 ± 0.03	a	0.987
T67	0.16 ± 0.02	a	0.13 ± 0.02	a	0.436
T65	0.12 ± 0.02	a	0.03 ± 0.02	b	0.005
T69	0.30 ± 0.05	a	0.10 ± 0.03	b	0.005
T68	0.37 ±0.09	a	0.14 ± 0.03	b	0.026

Table 1. Number of Leucoptera coffeella eggs in coffee genotypes.

Means followed by the same letter within rows do not differ by t-test (p>0.05).

In a no-choice bioassay with *L. coffeella* using genotypes selected from the previous oviposition preference assay, the insect parameters most affected were larval survival and leaf injury intensity. While the cultivar Arara provided high larval survival (99%), the genotypes T69 and T70 caused only 35-38% survival. These results confirm the presence of moderate level of antibiosis-resistance in the genotypes of cv. Siriema (Table 2).

Genotype	Larval survival (%)		Pupal survival (%)		Leaf injury scores (1-4)	
Arara	99.0 ± 0.9	a	96.4 ± 2.1	a	2.9 ± 0.04	a
T68	97.0 ± 3.0	a	98.6 ± 1.3	a	3.1 ± 0.08	a
T66	44.5 ± 8.3	b	98.0 ± 1.9	a	1.8 ± 0.1	b
T70	38.6 ± 5.2	b	100.0 ± 0.0	a	1.5 ± 0.1	b
T69	35.9 ± 7.7	b	100.0 ± 0.0	a	1.6 ± 0.2	b
T71	58.4 ± 9.7	b	82.8 ± 9.9	a	2.0 ± 0.2	b
p-value	<0.0001		0.078		<0.0001	

Table 2. Larval and pupal survival of *Leucoptera coffeella* in coffee genotypes.

Means followed by the same letter within columns do not differ by Tukey's test (p>0.05).

Experiments with coffee leaf miner are ongoing in the field and laboratory using kaolin-based products (aluminum silicate) as an IPM strategy. These products have been applied in coffee plantations to prevent scald burn injury in plants. Kaolin sprays have shown positive effects on pest reduction in other crops. The partial results obtained for coffee leaf miner showed that the highest kaolin doses decreased the number of *L. coffeella* eggs under a free-choice assay in the laboratory. Such an effect might be related to light reflection alteration on the leaf surface due to the white color of the kaolin powder. This, therefore, may have modified adult leaf miner behavior; yet, abrasive effects on insect cuticles or other unidentified factors may also be related.

Population fluctuation and resistance to coffee leaf miner in four *C. canephora* genotypes were evaluated in experimental plots in the field in Lavras (Santos, 2022). During the months of higher population peaks, mainly in October of each year, the genotypes Conilon 213 and Conilon LB1 were less infested, especially Conilon 213, which showed a moderate resistance level to coffee leaf miner.

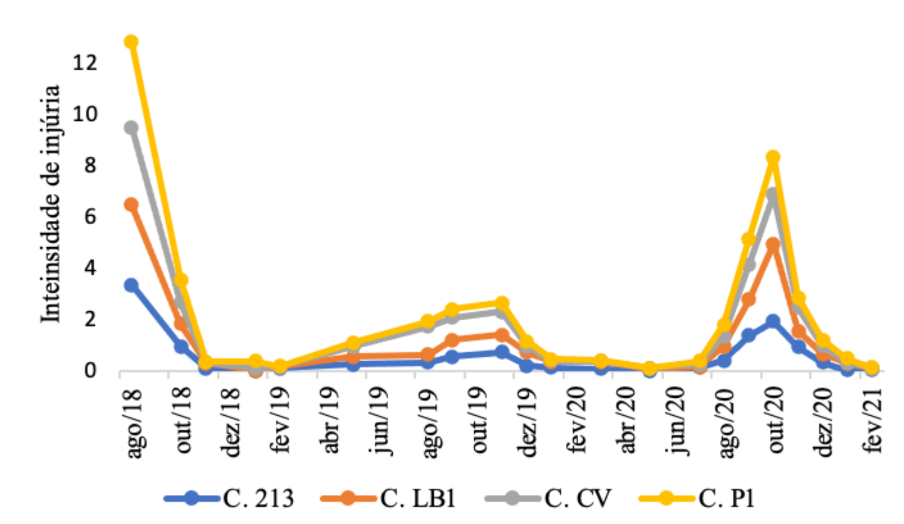

Figure 2. Infestations of *Leucoptera coffeella* in *Coffea canephora* genotypes in the field.

The same arabica coffee genotypes tested in the field (Lavras, MG) were tested for the resistance to coffee berry borer (Alves, 2021). In this study, the number of bored fruits and the presence of biological forms within the fruits were recorded. The berries were also classified during evaluations according to their maturation stages. This was made to exclude occurrence of resistance from phenological asynchrony, in which the phase of greater susceptibility of host plants coincides with lower pest population peaks and may lead to erroneous interpretation on the presence of resistance.

Among the main results (Alves, 2021), the lowest *H. hampei* infestation in the upper third of coffee plants was found in the cultivar Arañas RH. This cultivar, in turn, did not differ from Acauã, IPR 100, IPR 102, Arara, IPR103, Acauã Novo, Clone 312, Clone 224, Aranãs RV, Pau Brasil, and Asa Branca. In the middle third of plants, the cultivars IPR 103 and Arara had the lowest infestations, not differing from Acauã, IPR 100, Acauã Novo, Arañas RH, IPR 102, and Clone 224. The cultivar Siriema showed greater coffee berry borer infestation than the other cultivars in both thirds of plants. In the upper third, the cultivar Catiguá MG-3 had the second highest infestation, not differing from Catiguá MG2, Guará, Saira II, Catiguá MG-1, Araponga, IAPAR 59, Oeiras, and Catucaí Amarelo. In the middle third, the cultivar Catucaí Amarelo was the second most infested, not differing from Catiguá MG-3, Oeiras, Araponga, Catiguá MG-1, and Pau Brasil.

According to the results, cv. Siriema was highly susceptible and was not affected by fruit precocity regarding higher *H. hampei* infestation. These effects may have been overlapped on Catuaí Amarelo, IAPAR 59, and Araponga, which were moderately and earlier infested. The cultivars Aranãs RH, Acauã, Arara, IPR 103, IPR 100, and IPR 102 may have characteristics that affected *H. hampei* colonization, regardless of fruit maturation. Moreover, the cultivar Pau Brasil showed a higher percentage of fruits bored only on the edges. Such a result may indicate the presence of morphological characteristics or volatile or non-volatile compounds that caused insects to leave fruits after perforation. Those cultivars that stood out in terms of lower coffee berry borer infestations deserve further detailed research regarding plant resistance.

In coffee production, a uniform fruit maturation during harvest is stimulated by application of growth regulators, also called bioregulators. Potassium acetate is a precursor of aminoethoxyvinylglycine, which in turn, inhibits the enzyme 1-carboxylic acid-1-aminocyclopropane synthase (ACC synthase). This enzyme produces ethylene from 1-carboxylic acid-1-aminocyclopropane (ACC) in ripening fruits (Even-Chen et al., 1982). Increasing ethylene concentrations in fruit rises climacteric respiration, initiating ripening by increasing respiration rates and synthesis of enzymes related to flavor, aroma, color, and water loss (Taiz et al., 2017).

Field and laboratory studies (Dias, 2019; Martins, 2022) were performed to evaluate the effect of applying ethylene-synthesis inhibitor (Mathury™) on *H. hampei* colonization and development in fruits treated with different doses and application periods. Due to the mode of action of the bioregulator, its application could impair coffee berry borer colonization and affect oviposition and larval development, reducing pest infestation due to the influence on fruit and seed water contents, as humidity is a limiting condition for the pest development.

Since ethylene is one of the main phytohormones in signaling pathways and resistance to insects, along with jasmonic acid and salicylic acid (Souza; Boiça Júnior, 2014; Taiz et al., 2017), changes in its concentrations may have additional effects on *H. hampei* behavior and development.

In field experiments (Lavras, MG), ethylene-synthesis inhibitor (Mathury™) applications at 80 days after flowering (DAF) with 2 and 15 L ha^{-1}, and at 110 DAF with 15 L ha^{-1} caused, respectively, 84 and 93% reductions in the number of *H. hampei* pupae inside fruits collected from the middle third of arabica coffee plants. For *H. hampei* adults, reductions were by 50, 76, and 55% for treatments applied at 80 DAF with 2 and 15 L ha^{-1} and at 110 DAF with 2 L ha^{-1}, respectively. Moreover, *H. hampei* females showed a lower preference for fruits treated in the field at 80 DAF with 15 L ha^{-1} or at 110 DAF with 2 L ha^{-1} when compared to untreated fruits in a free-choice assay (Martins, 2022).

A complementary study on *H. hampei* development in fruits subjected to the same field treatments was evaluated in a no-choice assay in the laboratory (Dias, 2019). The results showed significantly lower adult survival (6.7 to 17.8%) in fruits treated with ethylene-synthesis inhibitor (Mathury™) at 80 DAF with 15 L ha^{-1} and 110 DAF with 2 and 15 L ha^{-1} compared to untreated coffee fruits (46.6%). The number of *H. hampei* larvae in fruits under the same treatments was also reduced (0.07 to 0.16 larvae) as compared to the control (1.46 larvae).

Other studies were carried out under field and laboratory conditions (Padilla, 2022) to evaluate IPM strategies for *H. hampei*. The treatments tested rotation or mixture of chemical insecticides (chlorpyrifos, acetamiprid+bifenthrin, and metaflumizone), entomopathogenic fungus *B. bassiana*, and an adjuvant (Openeem Plus™) based on neem extract (*Azadirachta indica* A. Juss.). The neem extract-based product may also have biostimulant effects on plants due to its constituent compounds, which are extracted from virtually all neem plant parts but the fruits and kernels.

In the field experiment, the strategy constituted by Chlorpyrifos+Openeem/Openeem/Clorpyrifos+Openeem in the first, second-, and third-monthly applications, respectively, stood out with the highest number of fruits without *H. hampei* adults in the second evaluation, reducing infestation by 55%. In the third evaluation, the applications of Sperto/Boveril/Verismo showed the highest number of bored berries without adults inside, and the adult infestation was reduced by 41% (Figure 3).

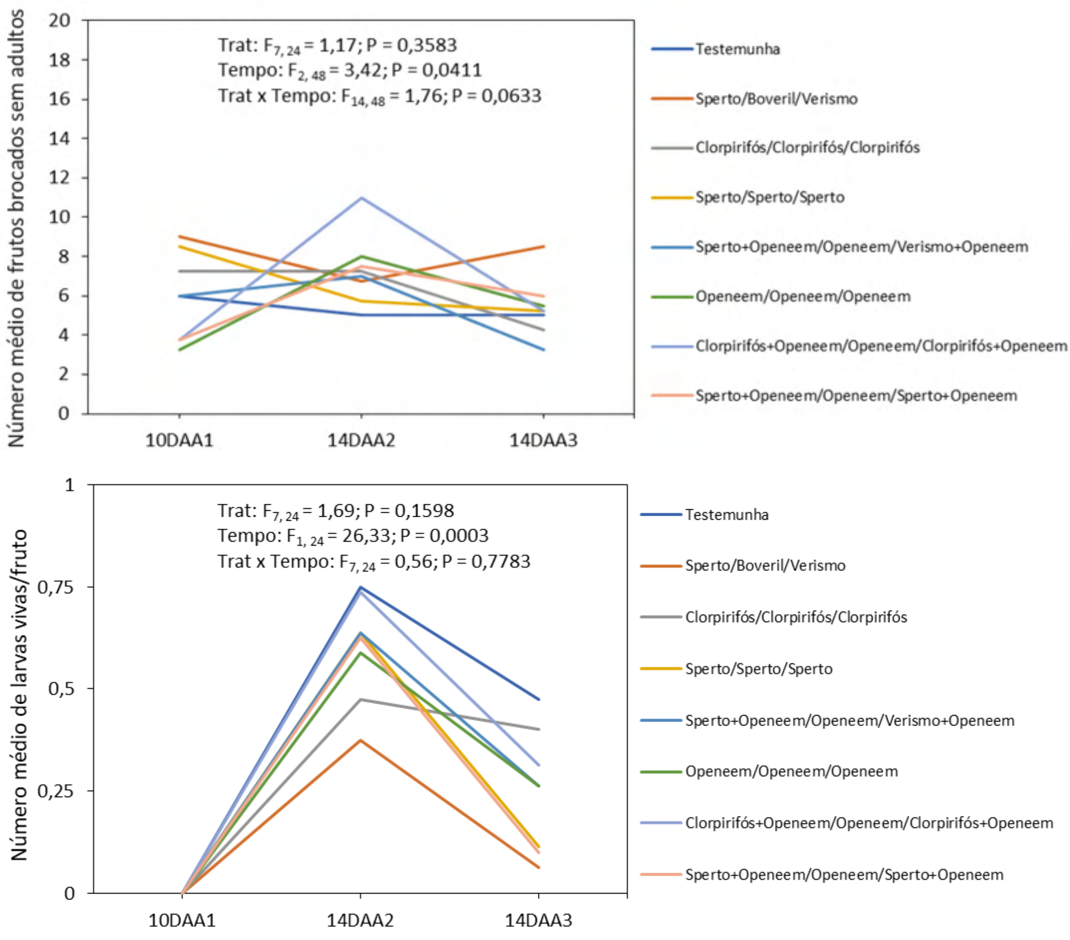

Figure 3. Numbers of bored berries without *H. hampei* adults (A) and larvae per fruit (B) in three evaluations after applications of insecticides, bioinsecticide, and neem extract-based adjuvant in rotation or mixture.

As for the number of larvae in fruits (Padilla, 2022), the treatment consisting of Sperto/Boveril/Verismo in three monthly applications, respectively, had the lowest mean number of live *H. hampei* larvae per fruit (50% control efficiency). In the third evaluation, the treatments Sperto/Boveril/Verismo, Sperto+Openeem/Openeem/Sperto+Openeem, and Sperto/Sperto/Sperto showed the lowest infestations of live larvae per fruit, reducing larval infestations by 87, 79, and 76%, respectively (Figure 3).

A field bioassay was conducted in *voile*-fabric cages attached to branches with cherry fruits in arabica coffee plants artificially infested with *H. hampei* adults after 40 days of neem extract (Openeem Plus™) application. As the main results of this field bioassay, the number of *H. hampei* eggs was significantly reduced with the application of the neem-based product

(4.92 eggs) relative to the control (7.92 eggs) without application (Padilla, 2022).

The effect of neem extract (Openeem Plus™) application over artificial diet on *H. hampei* biological development was evaluated in Petri dishes under laboratory conditions (PADILLA, 2022). The percentage of dishes with eggs was four-fold higher in the control treatment. The results were similar for *H. hampei* larvae and pupae. The number of adults was numerically higher in the control, while in dishes with artificial diet treated with neem extract, adults did not emerge until 40 days of evaluation (Figure 4). The number of eggs also showed a significant difference, being lower in artificial diet treated with neem extract. Based on the field and bioassay results (Padilla, 2022), neem extract impaired coffee berry borer performance, reducing oviposition of females fed fruits treated with the botanical product.

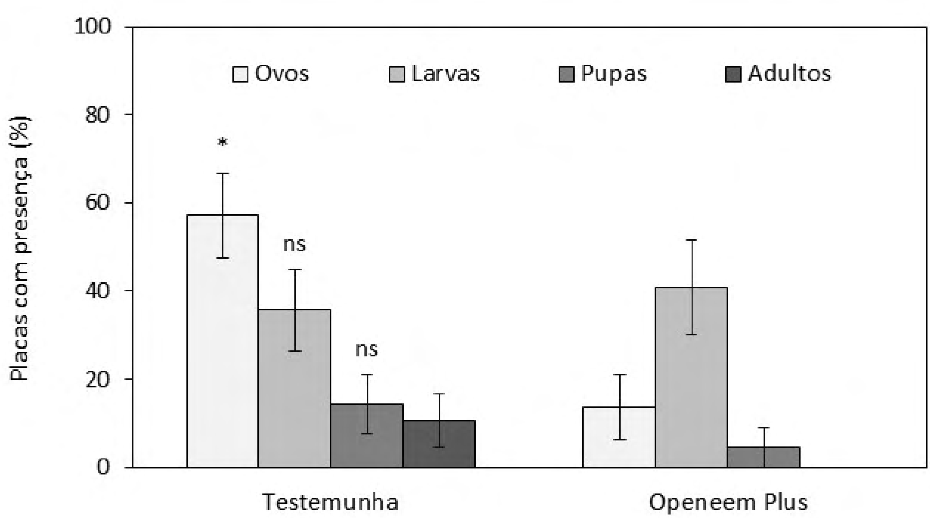

Figure 4. Percentage of *H. hampei* eggs, larvae, pupae, and adults in Petri dishes with artificial diet treated or not with neem extract adjuvant (Openeem Plus™).

The physiological effect of neem extract-based product (Openeem Plus™) reducing *H. hampei* oviposition can be explained by adult malnutrition in treated fruits, affecting egg production and maturation. This is because *H. hampei* is synovigenic, that is, insect feeding during the adult stage influences egg production.

The information generated from that research (Padilla, 2022) is relevant for coffee berry borer IPM. The proposed pest management strategies may contribute to reducing chemical insecticide applications and show neem extract compatibility with *B. bassiana*-

based bioinsecticide and with some insecticides. Still, further studies should be carried out to assess the ability of neem extract to trigger induced defense responses in coffee fruits against coffee berry borer.

6 | FINAL CONSIDERATIONS

Coffee leaf miner and coffee berry borer are the major biotic threats in terms of coffee productivity and quality for the main coffee-growing regions in Brazil. Such problems impact economic revenues from the production of this important agricultural commodity. These key pests of coffee crop are mostly controlled by application of chemical insecticides, which are often highly toxic. However, they do not provide the expected effects in terms of pest population reductions mainly due to cases of pest resistance. Therefore, novel IPM strategies must be developed and deployed in coffee plantations to improve pest control efficiency and sustainability.

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