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Coffee berry borer in conilon coffee in the Brazilian Cerrado: an ancient pest in a new environment

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Abstract

The aim of this study was to verify the occurrence of the coffee berry borer, *Hypothenemus hampei* (Ferrari), and to evaluate the population fluctuation of the pest in the Brazilian Cerrado (Federal District). The study was conducted, between November 2014 and October 2015, at Embrapa Cerrados (Planaltina/DF, Brazil) in an irrigated conilon coffee production area. In November 2014, 120 samples (ten berries/sample) were collected from berries that had fallen on the ground from the previous harvest. Between November 2014 and October 2015, insects were collected weekly, using traps (polyethylene terephthalate bottles) baited with ethyl alcohol (98 GL), ethyl alcohol (98 GL) with coffee powder, or molasses. Between January and July 2015, samples were collected fortnightly from 92 plants (12 berries per plant). All samples were evaluated for the presence of adult coffee berry borers. Samples from the previous harvest had an attack incidence of 72.4%. The baited traps captured 4062 *H. hampei* adults, and showed no statistical difference in capture efficiency among the baits. Pest population peaked in the dry season, with the largest percentage of captured adults occurring in July (31.0%). An average of 18.6% of the collected berries was attacked by the borer and the highest percentage incidence was recorded in July (33.2%). Our results suggest that the coffee berry borer, if not properly managed, could constitute a limiting factor for conilon coffee production in the Brazilian Cerrado.

Keywords: *Hypothenemus hampei*, *Coffea canephora*, robusta coffee, population dynamics, incidence, irrigation

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Introduction

Coffee is one of the most important agricultural commodities in the world. It is estimated that the worldwide coffee market has a 90 billion dollar turnover, involving some 500 million people from production to marketing (DaMatta *et al.*, 2010). Currently, the genus *Coffea* L. has about 124 species, but only *C. arabica* L. (arabica coffee) and *C. canephora* Pierre ex Froehn (conilon or robusta coffee) have economic importance

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and represent 99% of the world market (Willson, 1999; Davis *et al.*, 2006, 2011; DaMatta *et al.*, 2010).

Conilon coffee is originally from the equatorial region of Africa (Bridson &Verdcourt, 1988; Coste, 1992; Poncet *et al.*, 2007), and represents 41.2% of the coffee produced in the world with a production volume of 3.5 million tons (ICO, 2016). When compared with arabica coffee, conilon has a higher content of soluble solids and a higher yield after roasting, ideal characteristics for the manufacturing of soluble coffee (Farah, 2012). In order to reduce production cost and increase competitive capacity, conilon coffee has also frequently been used in blends with arabica coffee (Fonseca *et al.*, 2007).

In Brazil, conilon coffee accounts for 23.2% of all coffee produced, and the state of Espirito Santo accounts for 65.6% of the national conilon coffee production. Other states that produce conilon coffee are Bahia (15.6%), Rondonia (14.3%), Minas Gerais (2.9%), Mato Grosso (1.0%), and Para (0.1%) (Conab, 2016). Currently, there is a trend of expanding conilon coffee cultivation to areas previously considered to be marginal for growing this species, such as the Cerrado, mainly due to water restrictions. In these regions, during the dry season (4–7 months), evaporation exceeds precipitation, and in the rainy season, the pattern and amount of rainfall are less predictable. Without the use of irrigation, these conditions may restrict the potential yield of conilon coffee (Da Matta *et al.*, 2003). As a result, the Brazilian Cerrado presents great potential for the expansion of conilon coffee cultivation under an irrigated system, but studies on the development of a conilon coffee production system in the Cerrado are necessary.

The coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae), is the most important pest affecting coffee production around the world (Le Pelley, 1968; Baker, 1999; Barrera *et al.*, 2007; Vega *et al.*, 2009, 2015). It is estimated that in Brazil alone, annual losses caused by the coffee berry borer can reach $215–358 million (Oliveira *et al.*, 2013). In the main conilon coffee production areas of Brazil, this species has been confirmed as a major crop pest (Fornazier *et al.*, 2007).

This insect species causes problems for coffee crop because adult female borers make holes in coffee berries and lay their eggs. After hatching, the larvae feed on the seeds, causing a reduction in weight and quality, and often abscission of the berries. Most of the pest's life cycle is cryptic, except when females abandon the berry in which they were born to colonize new berries, thereby making it difficult to control their occurrence (Le Pelley, 1968; Baker, 1999; Damon, 2000; Vega *et al.*, 2009, 2015).

The Brazilian Midwest covers about 44–48% of the Cerrado biome (Pereira *et al.*, 1997; Sano *et al.*, 2008). This area of the Cerrado is highly favorable for the expansion of conilon coffee cultivation; however, except for the state of Mato Grosso, which is responsible for 1% of national production, in other states and in the Federal District, there is no cultivation record of this species (Conab, 2016).

The introduction of cultivated plant species into new environments requires prior investigation into the occurrence and behavior of populations of the main pests of the crop in that area. This plays a part in adopting preventative measures against such pest organisms.

Our hypothesis was that conilon coffee crops introduced to the central region of Brazil would be attacked by the coffee berry borer. We also hypothesized that irrigation could play a decisive role in the population dynamics of the pest; since, in other producing regions, the borer population peak occurs in the driest periods of the year.

Therefore, the aims of this study were to verify the presence of the coffee berry borer in conilon coffee under irrigated cultivation in the Cerrado biome (Federal District) and to evaluate the population fluctuation of the pest to support the adoption of control measures.

Materials and methods

Study area

The study was conducted in a 1 ha plantation of conilon coffee genotypes under center pivot sprinkler irrigation, located at Embrapa Cerrados in Planaltina, DF, Brazil (15°35′52.77″S; 47° 42′37.95″W; 982 m). The experimental area consisted of 3500 different plant genotypes, distributed in 30 lines. The coffee planting was carried out in 2009, with spacing of 3.5 m between rows, and 1.0 m between plants. Genotypes were the result of natural crossings in an experimental field of the cultivar, Robusta Tropical (EMCAPER 8151) of the Capixaba Research Company, and Rural Extension (EMCAPER) (Ferrão *et al.*, 2000). The management of irrigation was based on climate monitoring, and the plantation was irrigated every 5 days, according to the Cerrado Irrigation Monitoring Program (Rocha *et al.*, 2006). For uniformity of flowering, annually, irrigation was suspended in July and returned when 80% of flower buds reached of the E4 stadium, in September.

Coffee berry borer occurrence

To verify the occurrence of the coffee berry borer, the berries that remained in the fields after the November 2014 harvest were evaluated. These berries were used as it has been documented that high levels of pest infestation could be found in berries remaining post-harvest (Bustillo *et al.*, 1998; Castro *et al.*, 1998). Furthermore, since studies have shown no difference in borer populations between berries still on the plant or that have fallen to the ground (Fanton, 2001; Jaramillo *et al.*, 2009), and as few berries remained on the plants, it was decided to collect only berries that had fallen to the ground from the previous harvest (2013/14).

Four samples of ten coffee berries were collected in each of the 30 planting rows (120 samples, n = 1200 coffee berries). These samples were taken to the Entomology Laboratory at Embrapa Cerrados, where the berries were analyzed for the number of berries attacked, and the number of individual borers still present in the berries. Data were expressed as the mean number of berries attacked.

Samplings

Coffee berry borer population fluctuations were investigated using baited traps and by collecting berries from the plants.

Baited traps

Traps were constructed from 2 l polyethylene terephthalate bottles, a model adapted from Villacorta *et al.* (2001). In the central part of the bottle, a 12 × 10 cm window was made for the entry of insects, corresponding to 50% of the lateral body of the bottle. The bottles were then tied to the plant stem, with the bottom facing up. The bait compartment consisted of a plastic pot (10 cm length × 6 cm diameter), with holes on the sides to help spread the bait's smell, fixed to the inside of the 2 l bottles. A solution of water and detergent was placed at the bottom of the trap, corresponding to the neck of the bottle, to collect the insects.

In total, 30 traps were laid; ten traps containing each of the three types of attractive lures: ethyl alcohol (98 GL), ethyl alcohol (98 GL) with roasted and ground coffee powder (100 g coffee powder per liter ethanol), and molasses. We used a random block design with ten repetitions. The traps were distributed every three planting rows, with 10 m between lines and 50 m between traps in each line.

The evaluations of the number of borers in each trap were conducted weekly between November 2014 and October 2015. All collected insects were transported to the laboratory where, under a stereoscopic microscope (Stemi SV6, Zeiss, Jena, Germany), the coffee berry borers were separated from other insects. The number of insects belonging to the subfamily Scolytinae (Coleoptera: Curculionidae) was also recorded. The number of borers collected by each different type of bait was used to compare the collection efficiency of each bait.

Collection of berries on the plant

The evaluations were conducted between January and July 2015, the period that corresponds to the conilon coffee production season in the experimental area. Fortnightly, 12 fruits were collected per plant, from 92 plants (genotypes) in total. The berries were randomly collected from the lower, middle, and upper branches of each plant. The genotypes were selected on the basis of high productive potential (more productive) evaluated in the 2011/12, 2012/13, and 2013/14 harvests. In the laboratory, the samples were analyzed under a stereoscopic microscope, and the number of berries attacked by coffee berry borer, the position of the hole in the berry (crown, petiole, or in the middle of the berry), and the number of borers per berry were recorded.

Confirmation of the taxonomic identification of specimen collected in the studies was based on Vega *et al.* (2015). Voucher specimens were deposited in the Entomological Museum of Embrapa Cerrados (CPAC).

Data analysis

As the data related to number of borers collected during the experiment represent a quantitative variable with a cumulative frequency distribution, the weekly numbers of insects obtained for each trap, were added during the collection period. Box–Cox transformation was applied to the data set (Box & Cox, 1964) and normality was verified by the Shapiro–Wilk, Kolmogorov–Smirnov, Cramer–von Mises, and Anderson–Darling tests. Data were subjected to an analysis of variance using the general linear model PROC GLM (SAS Institute, 2001). The objective of this analysis was to determine whether there are statistically significant differences in the number of *H. hampei* adults collected in the sample period in relation to types of bait used in traps. The averages for each types of bait were compared by Tukey's test at the 0.05 level of probability (SAS Institute, 2001).

To measure the degree of association between the average monthly number of borers collected by baited traps, and the incidence of borers in berries collected on plants (genotypes), represented by the average monthly percentage of berries attacked, a correlation analysis (Spearman) was calculated. The same correlation analysis was also conducted between the dependent variables (quantitative) 'number of borers/trap and incidence of attacked berries', and the monthly values of the meteorological data (independent variables) – average monthly temperature, average monthly relative humidity and monthly cumulative rainfall – provided by the Biophysics Laboratory of Embrapa Cerrados. Correlation analyses were performed using Statistica software version 13 (Dell Inc., 2015). This non-parametric analysis, which is used for quantitative discrete variables (i.e., number of adult insects collected per trap) does not require data normality or linearity.

Results

Coffee berry borer occurrence

While investigating the berries remaining from the previous harvest (2013/14 season), 1220 adult coffee berry borers were found, with an average of 1.0 borer/berry, and roughly 72.4% berries attacked.

Baited traps

Throughout the sample period, 4062 adults of *H. hampei* were collected in the baited traps, representing 67.2% of all specimens of the subfamily Scolytinae (Coleoptera: Curculionidae). For the overall average number of borers collected from the three baits combined, as well as for the baits analyzed separately, there was a general increase in the number of borers from January to July, with the peak in July (fig. 1). From August, the month in which the coffee harvest occurs, low fruit availability led to a decrease in the population of the pest, with a return in population growth from September (fig. 1). It was observed that data presented normality (Shapiro–Wilk $W = 0.98$, $P = 0.84$; Kolmogorov–Smirnov $D = 0.07$, $P > 0.15$; Cramer–von Mises W-Sq = 0.02, $P > 0.25$ and Anderson–Darling A-Sq = 0.19, $P > 0.25$). There was no statistically significant differences among the number of borers collected using the different tested baits ($F = 0.44$; $P = 0.92$).

Collection of berries on the plant

Regarding the incidence of *H. hampei* present in conilon coffee berries still on the plant, 353 adult borers were collected from 10,730 berries. An average of 18.6% of berries attacked was recorded, and, on average, 0.05 borers/berry were found. It was observed that 69.5% of the perforations occurred on the crown area, 15.1% on the petiole, and 15.4% on the middle part of the berries. The trend of pest incidence increased between January and July, with the highest percentage occurring in July (33.2%) (table 1).

There was a positive correlation between the fluctuation in borer population, determined using baited traps, and the incidence of berries attacked, determined by collecting berries on plants ($R^2 = 0.93$; $P = 0.002$). No correlation was observed between meteorological data (monthly average air temperature, air humidity, and monthly accumulated rainfall) and the fluctuation in borer population or incidence of berries attacked.

Discussion

Although the coffee berry borer is the most important pest of coffee crop worldwide (Le Pelley, 1968; Baker, 1999; Barrera

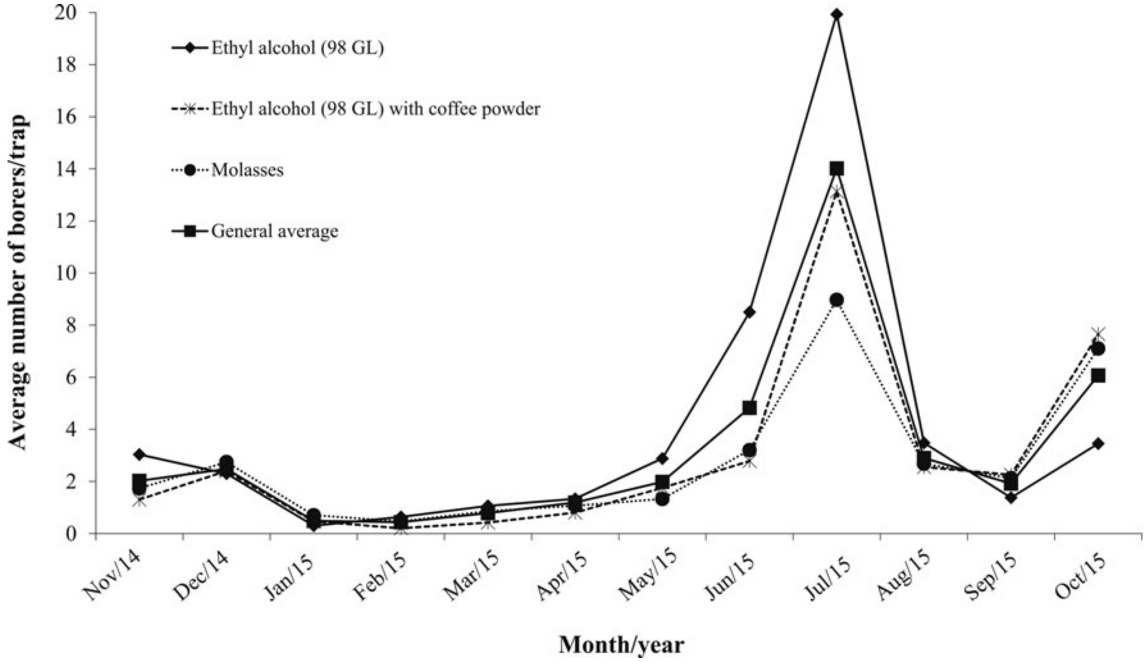

Fig. 1. Average number of adult coffee berry borer (*Hypothenemus hampei*) collected using baited traps [ethanol (98 GL), ethanol (98 GL) with roasted and ground coffee powder and molasses of sugarcane] in an irrigated conilon coffee crop located in the Federal District (Brazil) between November 2014 and October 2015.

Table 1. Monthly percentage of coffee berry borer (*Hypothenemus hampei*) incidence on berry, average percentage of perforations on three different parts of the berry surface (petiole, central, and crown areas) and the average number of borers per berry on conilon coffee plants under irrigation in the Federal District, between January and July 2015.

Month	Berries attacked (%)	Parts of the berry (%)			Borer/ berry
		Crown	Middle	Petiole	
January	16.4	69.4	17.7	12.9	0.0000
February	6.0	81.8	7.8	10.4	0.0000
March	9.2	79.1	11.9	9.0	0.0000
April	17.9	53.3	21.3	25.4	0.0017
May	16.5	58.9	23.6	17.5	0.0225
June	31.2	58.7	16.7	24.6	0.0150
July	33.2	85.6	8.7	5.7	0.3200
Average	18.63	69.5	15.4	15.1	0.0513

et al., 2007; Vega *et al.*, 2009, 2015), to our knowledge, this is the first recording of its presence in Federal District, and its occurrence in conilon coffee cultivation in Central Brazil. This pest is already present in all arabica coffee regions in Brazil. Direct observation of pest presence, from berries on plants or that had fallen to the ground, and indirect observation of pest presence, from collecting adults using baited traps, suggest that the coffee berry borer is capable of rapidly colonizing conilon crops in the Cerrado region, which is intended for crop expansion.

The high incidence of *H. hampei* in berries remaining from the previous harvest (above 70%) demonstrates the importance of cultural control. These include harvesting effectively, and, especially, the technique called 'repase'. This practice involves the collection of all stages of coffee berry from plants and the ground, immediately after the harvest (Waterhouse & Norris, 1989; Bustillo *et al.*, 1998; Castro *et al.*, 1998; Aristizabal *et al.*, 2002; Jaramillo *et al.*, 2006), preferably before the beginning of the rainy season, since high temperature and relative humidity stimulate coffee berry borer females to emerge and search for new berries in which to begin the next cycle (Baker *et al.*, 1992; Baker & Barrera, 1993).

The number of borers collected, and the percentage of berries attacked, showed growth between January to February and July, with a peak at the end of the coffee harvest (July). It is possible that this occurred because the number of generations and the size of the insect's population increase during the crop cycle, reaching 4–5 times higher during the ripening stage of berries; this stage, which has higher content of dry matter, is most attractive and suitable for the biological development of the pest (Alonzo, 1984; Bustillo *et al.*, 1998; Baker, 1999). In studies conducted in Rondonia state (Brazil) with robusta coffee, the behavior of the borer populations was similar. The population increased between September and May, peaking near harvesting time (May) (Costa *et al.*, 2001). Moreover, in Minas Gerais state (Brazil), from 2009 to 2012, the population of borers in arabica coffee berries also grew during berry development, and peaked between June and July (Silva *et al.*, 2013). In studies carried out in Ethiopia (Africa), populations of the coffee berry borer showed a similar population growth to that observed in the present study, with a population increase from January, and peak population between June and August, both for berries collected on the plant or those fallen to the ground (Mendesil *et al.*, 2004).

Although studies have shown no difference in borer populations between berries still on the plant or that have fallen to the ground (Fanton, 2001; Jaramillo *et al.*, 2009), in this study, a higher percentage of berries attacked and a higher number of borer/berry were observed in berries fallen on the ground (72.4% and 1.0 borer/berry) when compared with berries collected on plants (maximum of 33.2% and 0.32 borer/berry in July). This difference, however, may be due to the period of the year in which the evaluations were performed. Evaluations of berries fallen on the ground was carried out in November, 3 months after the coffee harvest. In this period, few berries are left unharvested, allowing the concentration of the population of *H. hampei*, that usually pass the interharvest period semi-inactive inside the remaining berries (Baker *et al.*, 1992). On the other hand, evaluations with berries from the plants were conducted during coffee production cycle (January–July) causing a dilution effect of the borer population as a function of the greater number of berries available.

The population dynamics and pattern of the coffee berry borer infestation are highly related to climatic factors, such as precipitation and relative humidity (Baker *et al.*, 1992). Although we did not detect a significant correlation between meteorological data and the population of *H. hampei* adults, or percentage of berries attacked, other studies have. In Brazil, it has been shown that populations of the coffee berry borer are negatively related to the increase of rainfall intensity between January and March, and that the growth of the borer population is favored with the onset of the dry season in April, and with high temperatures (Souza & Reis, 1997; Ferreira *et al.*, 2000). However, studies in Africa have shown a positive correlation between the *H. hampei* adult population and rainfall (Mendesil *et al.*, 2004). In general, in the Federal District, high volumes of rain occur between January and March, and the dry season begins in April, with relatively high average temperatures. These conditions could favor the growth of the coffee berry borer population in this region. In this study, however, there was no negative effect of humidity on the borer population, since the crop received center-pivot irrigation during the dry season (March–July, 2015) that could, theoretically, cause a reduction in the population of the pest. These results suggest that the increase in air humidity and the wetting of plants provided by irrigation do not limit the growth of the pest population.

Several studies claim that the population of coffee berry borer can be monitored effectively using baited traps, but that collection efficiency depends on factors such as color, trap model, bait type, and odor release rates (Silva *et al.*, 2006*a*, *b*; Dufour & Frérot, 2008; Fernandes *et al.*, 2014; Aristizábal *et al.*, 2015). We tested the use of a simple trap and several affordable baits for the monitoring of *H. hampei*. There were no statistical differences in collection efficiency between the baits investigated. Thus, we are the first to propose the use of molasses to bait the coffee berry borer, an attractive bait, cheap, affordable and non-flammable as alcohol. The efficiency of traps for monitoring the pest population is supported by high correlation between adults captured by traps and the percentage of berries attacked ($R = 0.93$; $P = 0.002$). Other studies have also shown positive correlations between the number of coffee berry borer adults collected in traps and the incidence of berries damage (Mathieu *et al.*, 1999; Pereira *et al.*, 2012). Establishing a consistent correlation between trap data and the incidence of berries attacked by the pest is important as data from traps may, in the future, be used as an alternative way to determine the levels of pest control, instead of calculating the percentage of berries attacked (Pereira *et al.*, 2012).

With respect to site of perforation in the berries, the results are similar to other studies conducted with arabica coffee, which found that most berry perforation occurs in the crown region (Bergamin, 1943; Costa & Faria, 2001). This preference is due to this part of the berry having greater roughness, allowing the borer grab the berry to perforate it (Costa & Faria, 2001).

The economic threshold (or action threshold) for coffee berry borer, established in arabica coffee, ranges from 4.3 to 5% of berries attacked (Souza & Reis, 1997; Fernandes *et al.*, 2011), and for conilon coffee, the economic damage threshold was therefore 2.34%, for an average yield of 800 kg ha^{-1} of green coffee (Wegbe *et al.*, 2003). In this study, in general, all borer infestation sampling dates exceeded the economic threshold; the average infestation rate ranging from 6.0 to 33.2% (table 1). Consequently, the implementation of control measures is required. These results are important because they show that the cultivation of conilon coffee in the Cerrado region is susceptible to attack by this pest, and that crop monitoring is necessary from the beginning of the harvest.

Our results suggest that the coffee berry pest, *H. hampei*, if not properly managed, will constitute a limiting factor in the production of conilon coffee in areas of expansion, including the Brazilian Cerrado. This is due to the high infestation rates presented by most conilon genotypes tested. However, management strategies based in cultural control, including the technique known as 'repase' and the constant monitoring of crops through sampling, can be important tools for successfully cultivating this crop in the new environment.

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