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Control of coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae) with botanical insecticides and mineral oils

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ABSTRACT. The objective of this study was to evaluate botanical oils, mineral oils and an insecticide that contained azadirachtin (ICA) for the control of *Hypothenemus hampei*, in addition to the effects of residual castor oil. We evaluated the effectiveness of the vegetable oils of canola, sunflower, corn, soybean and castor, two mineral oils (assist® and naturol®), and the ICA for the control of *H. hampei*. The compounds were tested at a concentration of 3.0% (v v^{-1}). The median lethal concentration (LC_{50}) was estimated with Probit analysis. The oil of castor bean and extract of castor bean cake were also evaluated at concentrations of 3.0% (v v^{-1}) and 3.0% (m v^{-1}), respectively. The mortality rates for *H. hampei* caused by the ICA and the castor oil were 40.8 and 53.7%, with LC_{50} values of 6.71 and 3.49% (v v^{-1}), respectively. In the castor oil, the methyl esters of the fatty acids were palmitic (1.10%), linoleic (4.50%), oleic (4.02%), stearic (0.50%) and ricinoleic acids (88.04%). The extract of the castor bean cake was not toxic to *H. hampei*. The persistence of the castor oil in the environment was low, and the cause of mortality for *H. hampei* was most likely the blockage of the spiracles, which prevented the insects from breathing.

Keywords: *Ricinus communis*, *Azadirachta indica*, median lethal concentration, fatty acids, toxicity.

Controle da broca-do-café, *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae) com inseticidas botânicos e óleos minerais

RESUMO. O objetivo desse trabalho foi avaliar inseticidas botânicos, óleos minerais e o inseticida contendo azadiractina (ICA) no controle de *Hypothenemus hampei*, bem como o poder residual do óleo de mamona. Para isso foram utilizados os óleos vegetais de canola, girassol, milho, soja e mamona, os óleos minerais assist® e naturol® e o ICA, testados na concentração de 3,0% (v v^{-1}). A concentração letal média (CL_{50}) foi estimada usando a análise de Probit. O óleo e o extrato da torta de mamona foram avaliados na concentração de 3,0% (v v^{-1}) e 3,0% (m v^{-1}), respectivamente. O ICA e o óleo de mamona causaram 40,8 e 53,7% de mortalidade de *H. hampei*, e apresentaram CL_{50} de 6,71 e 3,49% (v v^{-1}), respectivamente. No óleo de mamona foram identificados os ésteres metílicos dos ácidos graxos: palmítico (1,10%), linoleico (4,50%), oleico (4,02%), esteárico (0,50%) e ricinoleico (88,04%). O extrato da torta da semente de mamona não apresentou toxicidade sobre *H. hampei*. O óleo de mamona apresentou baixa persistência no ambiente. O óleo de mamona causou a mortalidade de *H. hampei*, sendo provavelmente devido ao bloqueio dos espiráculos, impedindo a respiração desse inseto.

Palavras-chave: *Ricinus communis*, *Azadirachta indica*, concentração letal média, ácidos graxos, toxicidade.

Introduction

The coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae), is one of the most important phytosanitary problems for the coffee crop (Vega Infante, Castillo, & Jaramillo, 2009; Vega et al., 2014). The damage caused by this beetle pest to the coffee fruits decreases the weight of the beans and changes the type, classification and flavour of the coffee beverage (Vega et al., 2009).

The phytosanitary management of the pest indicates the use of control tactics that are based on a cost-benefit analysis and a low operational effect on the agroecosystem. Thus, because of the choice of society to reduce the environmental effects from the management of pests, the research on the use of botanical insecticides has increased in recent years (Isman & Grieneisen, 2014). Among the substances extracted from plants, the azadirachtin obtained from *Azadirachta indica* A. Juss (Meliaceae) is an important alternative in pest management (Isman, 2006; Janini et al., 2011; Pinto, Barros, Torres, & Neves, 2013). The chemical constituent of this pesticide interferes with the synthesis and the release of hormones (ecdysteroids) from the prothoracic gland, which leads to incomplete ecdysis in immature insects (Isman, 2006). Furthermore, the azadirachtin has an antifeedant effect for a wide range of insects and may cause sterility in female insects (Isman, 2006). The emulsifiable oil, the extracts of leaves and the seeds of neem were repellent to and increased the mortality of the coffee berry borer (Depieri & Martinez, 2010).

The derivatives of the castor bean (*Ricinus communis* L., Euphorbiaceae) also have potential in pest management (Ramos-López, Pérez, Rodríguez-Hernández, Guevara-Fefer, & Zavala-Sánchez, 2010; Tounou et al., 2011), with products that showed insecticidal activity against *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) through effects on the duration and viability of the larval and pupal stages and on the weight reduction of the pupae (Ramos-López et al., 2010). The insecticidal action of the castor bean derivatives was also demonstrated for *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), *Plutella xylostella* L. (Lepidoptera: Plutellidae) and *H. hampei* (Bestete, Pratissoli, Queiroz, Celestino, & Machado, 2011; Rondelli et al., 2011; Tounou et al., 2011; Pérez, Zayas, Villa, Puentes, & García, 2012).

In addition to the derivatives of vegetables, mineral oils are also used to control insect pests (Nicetic, Cho, & Rae, 2011). The primary cause of death of arthropods with mineral oil is likely the blockage of the trachea or spiracles, and the lack of oxygen causes death to the insects (Stadler, Zerba, & Buteler, 2002; Stadler & Buteler, 2009). However, the mineral oils also affect the integument, with the ruptures of cell membranes and browning. The behaviour of insects is affected by these oils with typically repellent effects on oviposition and feeding, in addition to effects on the nervous system (Najar-Rodríguez, Walter, & Mensah, 2007; Najar-Rodríguez, Lavidis, Mensah, Choy, & Walter, 2008; Stadler & Buteler, 2009). Thus, the objectives of this study were to evaluate the botanical insecticides, the mineral oils, an insecticide containing azadirachtin (ICA) and the effects of residual castor oil for the control of the coffee berry borer.

Material and methods

The experiment was conducted at the Entomology sector of the Nucleus of Scientific & Technological Development in Phytosanitary Management (Nudemafi) of the Agrarian Sciences Centre of the Federal University of Espirito Santo (CCA-UFES). The environmental conditions of the experiment were a temperature of 25±1°C, a relative humidity (RH) of 60±10% and a photoperiod of 12:12 h light:dark. The rearing and the maintenance of *H. hampei* were according to Dalvi and Pratissoli (2012).

Identification of the chemical constituents of castor oil

The transesterification reaction was performed using 150 mg of castor oil and methyl-benzene alcohol at the ratio of 4:1, according to the methodology proposed by Folch, Lees and Sloane-Stanley (1957) and modified by Lepage and Roy (1986). The mixture was heated at 100°C for 60 min. Then, an aliquot of 10 μL of the transesterified sample was dissolved in 1000 μL of dichloromethane, and the sample was injected, in duplicate, into a gas chromatograph coupled with a mass spectrometer (GC/MS). The analysis was performed using the electron impact ionization (70 eV energy), with helium as the carrier gas (flow rate = 1.47 mL min.$^{-1}$) and a fused silica capillary column with the stationary phase RTX-5MS; the column was 30 m long with an internal diameter of 0.25 mm. We used the following temperature program: an initial oven temperature of 100°C (5 min.), which was followed by an increase of 10°C min.$^{-1}$ up to 280°C for 10 min. The temperature of the injector and the detector were maintained at 250°C. The 1.0 μL sample was injected in split mode, with a split ratio of 1:5, and in a continuous scan mode (interval m z^{-1} 33-808 a.m.u.). The identification of the compounds was performed with comparisons of the mass spectra in the NIST library (National Institute of Standards and Technology [NIST], 2015).

The quantification of the chemical constituents of the castor oil was performed on a gas chromatograph (SHIMADZU GC-2010 Plus, SINC do Brazil Scientific Instruments CO., São Paulo, São Paulo State, Brazil) equipped with a flame ionization detector (GC-FID); the column type was identical to the one that was previously described. The carrier gas was nitrogen (0.80 mL min.$^{-1}$; 85.2 kPa), and temperatures of the injector and the detector were 250 and 280°C, respectively. The temperature programme in the oven was identical to that used in the analysis with the GC-MS. The 1.0 μL sample was injected in split mode, with a split ratio of 1:30.

Tests of insecticidal activity of botanical insecticides, mineral oils and the insecticide containing azadirachtin (ICA)

For the experiments, we used the vegetables oils of soybean (Bunge Alimentos S.A.), sunflower (Bunge Alimentos S.A.), canola (Olvebra Indústria S.A.), corn (Bunge Alimentos S.A.) and castor; the insecticide that contained the azadirachtin (ICA) (Sempre Verde Killer Neem®; Active ingredient: 0.3% azadirachtin); and the mineral oils assist® (BASF – The Chemical Company) and naturol® (Farmax – Distribuidora Amaral LTDA). The compounds were acquired in the stores of the segment, with the exception of the castor oil. The castor seeds (*R. communis*), IAC 80, were acquired by the Agronomic Institute of Campinas (IAC) and were cold-pressed to extract the oil; this product was stored in a container wrapped with foil and hermetically sealed.

The experimental unit was a gerbox® (6 cm diameter x 2 cm) that was lined with filter paper that contained 15 newly emerged female coffee berry borers. Each treatment had 5 replications. In this bioassay, the oils were tested at a concentration of 3.0% (v v^{-1}), and in the preparation of the solutions, an adhesive surfactant 0.01% (w v^{-1}) (PS Tween® 80; Dynamic Contemporary Chemistry LTDA) and acetone 2% (v v^{-1}) were added. The control was prepared with deionized water and the adhesive surfactant 0.01% (w v^{-1}) and the acetone 2% (v v^{-1}). The female coffee berry borers were sprayed with a Potter Spray Tower® at a pressure of 15 pounds per square inch (PSI), which applied a volume of 5.5 mL per replicate. After the spraying, 0.15 g of ground coffee/gerbox® was offered as food. The mortality analysis was performed seven days after the release of the females, with a correction according to Abbott's formula (Abbott, 1925). The experimental design was completely randomized, and the data were subjected to analysis of variance. The means were grouped using the Scott-Knott grouping method, at 5% probability.

The LC_{50} values were estimated for the treatments that caused corrected mortality that exceeded 40.0%. To estimate the lethal concentrations, a series of eight concentrations on the logarithmic scale were used. The lower limit (the concentration that caused the deaths of approximately 15% of the insects) and the upper limit (the concentration that caused the deaths of more than 50% of the insects; mortality above 95% did not occur, and therefore, the LC_{90} was not calculated) were determined in preliminary tests, along with the respective controls. The lower and upper limits of the LC_{50} for the ICA were 0.5 and 10.0% (v v^{-1}), respectively; whereas for the castor oil, the lower and upper limits were 0.5 and 5.0% (v v^{-1}), respectively. The LC_{50} value was estimated with the Probit analysis using the POLO-PC program, with a confidence interval of 95% (Leora Software, 1987).

The derivatives of castor oil and cake were compared for insecticidal activity. The extract of the castor bean cake was obtained from 20 g of ground cake in a crucible. The vegetable material was transferred to a beaker that contained a KH_2PO_4 buffer solution, NaCl, and Na_2HPO_4, with masses of 3.40, 0.88, and 3.55 g L^{-1} of deionized water (pH 6.0), respectively. The mixture was placed on a magnetic stirrer for 30 minutes and then was filtered through a tissue 'voile'. The extract was diluted to the concentration of 3% (w v^{-1}) of the mass of the cake using the previously described buffered solution. In the control, only the buffered solution was used. The experimental unit was as described previously, and each treatment had 5 replications. The mortality analysis was performed seven days after the release of the females, with a correction according to Abbott's formula (Abbott, 1925). The experiment consisted of two treatments in a completely randomized experimental design, and the data were subjected to analysis of variance. The means were compared with F-tests at 5% probability.

Effect of residual castor oil

In this experiment, the experimental unit was identical to that described above, and each treatment had 5 replications. The treatment concentrations of castor oil were 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% (v v^{-1}), with the control without the oil (0.0% v v^{-1}). In the preparation of the solutions, the adhesive surfactant, Tween® 80 PS, 0.05% (v v^{-1}), was added. The ground coffee (0.15 g of ground coffee/gerbox®) was sprayed with a Potter Spray Tower® at a pressure of 15 pounds per square inch (PSI), which applied a volume of 5.5 mL per replicate. We examined the infestations of the coffee berry borer females at 0 (immediately after application), 1, 2, 3, 4 and 5 days after application. The mortality analysis was performed seven days after the release of the females, with a correction according to Abbott's formula (Abbott, 1925). The experimental design was completely randomized in a split-plot design in time with 6 concentrations of castor oil and 6 sample times after application (concentration of castor oil x time after application). The data were subjected to analysis of variance. The data were also subjected to regression analysis at 5% probability to determine the effects of the castor oil concentrations and the times after the application on the mortality of the coffee berry borers.

Results and discussion

Several features of the castor oil separated this compound from the others, such as the lowest iodine index and the highest viscosity, which are properties that are directly related to the chemical composition (Table 1). The saponification index indicates the mean molecular weight of the fatty acids that are esterified to glycerol in the triacylglycerol molecule, i.e., a high saponification index indicates the presence of fatty acids with low molecular weights, and vice versa. According to Nabil and Yasser (2012), the insecticidal activity of *Jatropha curcas* L. (Euphorbiaceae) seed oil on *Sitophilus granarius* L. (Coleoptera: Curculionidae) was related to the presence of high molecular weight fatty acids, which might also be an important factor in the insecticidal activity of the castor oil.

Among the tested vegetable oils, only the castor oil contained the ricinoleic fatty acid ester, which also had the lowest levels of the esters of palmitic, oleic, linoleic and linolenic fatty acids (Table 1). The profile of the fatty acids in the castor oil was obtained after the chromatographic analysis of the compounds in the mixture of the transesterification reactions (Figure 1). The chromatographic profile showed consistency, as expected for the castor oil, because of the fatty acid methyl esters that were identified, i.e., palmitic ($C_{16:0}$; 1.10%), linoleic ($C_{18:2}$; 4.50%), oleic ($C_{18:1}$, 4.02%), stearic ($C_{18:0}$, 0.50%) and ricinoleic (12-OH 9-$C_{18:1}$; 88.04%). The ricinoleic acid content, the primary component of castor oil, was similar to the contents that were reported for castor oil in other studies, 84.2 and 90.2% (Conceição et al., 2007; Salimon, Mohd Noor, Nazrizawati, Mohd Firdaus, & Noraishah, 2010).

The mortality of the coffee berry borers caused by the vegetable oils, the mineral oils and the ICA was significantly different ($F_{7:39}$ = 6.49, P = 0.0001; Table 2). The lowest mortality of *H. hampei* was caused with the two mineral oils (naturol® and assist®) and the vegetable oils of canola, corn, soybean and sunflower, and the mortality ranged from 13.6 to 30.3% (Table 2). Although the difference between them was not significant, the ICA (40.8%) and the castor oil (53.7%), with both at a concentration of 3.0% (v v^{-1}), caused the highest mortalities of the coffee berry borer (Table 2). The extract of the castor bean cake had no insecticidal effect on the coffee berry borers.

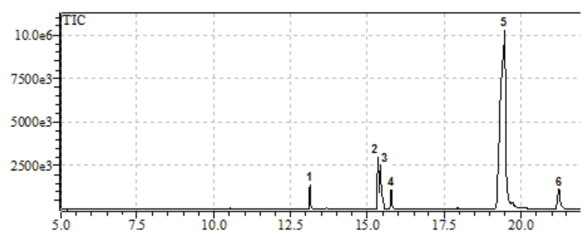

Figure 1. Chromatogram of the castor oil, variety IAC 80, after the transesterification reaction. 1 – $C_{16:0}$; 2 – $C_{18:2}$; 3 – $C_{18:1}$; 4 – $C_{18:0}$; 5 – 12-OH $C_{18:1}$; and 6 – UI (unidentified).

The ICA and the castor oil had LC_{50} values of 6.71 and 3.49% (v v^{-1}), respectively, for the coffee berry borer (Table 2). Although the difference was not significant between the LC_{50} values of the ICA and the castor oil, the ratio of the castor oil toxicity to the ICA toxicity was 1.92-fold higher (Table 2).

The effects of the mineral oils (naturol® and assist®) and the vegetables oils of canola, corn, soybean and sunflower likely occurred because the oils covered the openings of the spiracles of the insects, which led to asphyxiation and death. In some cases, researchers reported that the asphyxiation was caused by a blockage of spiracles and/or trachea as the primary mode of action of the mineral and vegetable oils (Law-Ogbomo & Egharevba, 2006; Stadler & Buteler, 2009; Egwurube, Magaji, & Lawal, 2010).

Table 1. Physico-chemical characteristics of the vegetable oils.

Chemical composition (%)[1]	Canola[2]	Sunflower[2]	Corn[2]	Soybean[2]	Castor bean[3]
Palmitic acid ($C_{16:0}$)	3.75	5.70	10.47	9.90	1.10
Stearic acid ($C_{18:0}$)	1.87	4.79	2.02	3.94	0.50
Oleic acid ($C_{18:1}$)	62.41	15.26	24.23	21.35	4.02
Ricinoleic acid ($C_{18:1}$)	-	-	-	-	88.04
Linoleic acid ($C_{18:2}$)	20.12	71.17	60.38	56.02	4.50
Chemical constants					
Saponification (mg KOH g^{-1})	168-181	186-198	187-195	189-195	180.30
Iodine (g I_2 100 g^{-1})	94-120	136-148	103-135	124-139	62.76
Physical constants					
Factor of refraction (40ºC)	1.465-1.469	1.467-1.470	1.465-1.468	1.466-1.470	1.479
Viscosity (cP) (30ºC)	50.50	41.30	47.40	41.20	332.00

[1]Number of carbon atoms: number of double bonds; [2]References: Conceição et al. (2007); Zambiazi, Przybylski, Zambiazi and Mendonça (2007); Brock et al. (2008); Salimon et al. (2010); and Codex Alimentarum (2014); [3]Oil composition used in the experiment.

Table 2. Corrected mortality (%) of the female coffee berry borers caused by 3.0% (v v^{-1}) vegetable oils, mineral oils and the insecticide containing azadirachtin. The median lethal concentration (LC_{50}) values were determined at 25±1°C, a RH of 60±10% and a photoperiod of 12:12 hours light:dark.

Oils	Mortality[1]	N[2]	Slope±SE[3]	LC_{50}[4] (% v v^{-1})	RT_{50}[5]	χ^2 (DF)[6]
Naturol®	13.6±2.99 b	-	-	-	-	-
Assist®	16.0±5.71 b	-	-	-	-	-
Canola	25.4±5.54 b	-	-	-	-	-
Corn	26.5±4.10 b	-	-	-	-	-
Soybean	29.0±2.89 b	-	-	-	-	-
Sunflower	30.3±7.46 b	-	-	-	-	-
ICA[7]	40.8±5.68 a	574	1.71±0.25	6.71 (5.35 – 8.87) a	-	4.05 (5)
Castor bean	53.7±4.68 a	521	1.65±0.33	3.49 (2.65 – 5.52) a	1.92	2.08 (4)

[1]Means (± SE) followed by the same lowercase letters in a column do not differ at 5% probability by the Scott-Knott grouping method; [2]Number of insects used in the LC_{50} bioassay; [3]Standard error (means followed by same letter in a column do not differ by the standard error); [4]Lethal concentration (LC_{50}) and confidence interval of the LC_{50} at 95% probability (95% CI) (means followed by same letter in a column do not differ by the 95% CI); [5]Reason toxicity = higher LC_{50}/lower LC_{50}; [6]Chi-square and degrees of freedom; and [7]Insecticide containing azadirachtin (ICA), with the trade name of Sempre Verde Killer Neem® (SVKN).

The castor oil was physicochemically differentiated from the other vegetable oils primarily because of the high ricinoleic acid content and the high viscosity (Table 1). The castor oil consisted of 88.04% ricinoleic acid; and the effects of the ricinoleic acid on the morphophysiology of the ovaries and the salivary glands of *Rhipicephalus sanguineus* (Latreille) (Acari: Ixodidae) led to the avoidance of two important processes: reproduction and feeding (Arnosti et al., 2011a, 2011b; Sampieri et al., 2013).

The insecticidal activity of castor oil was demonstrated on pests such as *S. frugiperda*, *H. zea* and *P. xylostella* (Ramos-López et al., 2010; Bestete et al., 2011; Rondelli et al., 2011; Tounou et al., 2011). However, for the coffee berry borer, only the extract of the green leaves of castor oil plants (2.2 g L^{-1} of boiled water) was evaluated, which reduced the number of individuals per sample, when analysed 72 hours after application (Pérez et al., 2012). For the neem oil (Dalneem®, 0.1% (v v^{-1}) of azadirachtin; Dalneem Brazil), the mortality of and the repellency to *H. hampei* caused by neem oil resulted in a reduced number of grains damaged by this pest (Depieri & Martinez, 2010). The authors found mortality of *H. hampei* up to 88.3% when the females and the beans were sprayed with a 1% (v v^{-1}) aqueous solution of emulsifiable neem oil. They also found that the number of brocades of coffee beans was lower when the neem oil (13.8%) was applied compared with the control (64.6%).

An interaction was found between the concentration of castor oil and the days after application on the mortality of the coffee berry borers ($F_{25:179}$ = 2.22; P = 0.0018; Figures 2 and 3). The mortality of the coffee berry borer females released 0, 1, 3, 4 and 5 days after the application of castor oil was adjusted to the linear model, i.e., an increase in mortality occurred with the increase in the concentration of the castor oil (Figure 2). However, on the second day after application of the product, the coffee berry borer mortality remained constant as a function of concentration, with a mean of 10.83% (Figure 2). This result was related to the low mortality of the coffee berry borers, which occurred even at the higher concentrations of castor oil.

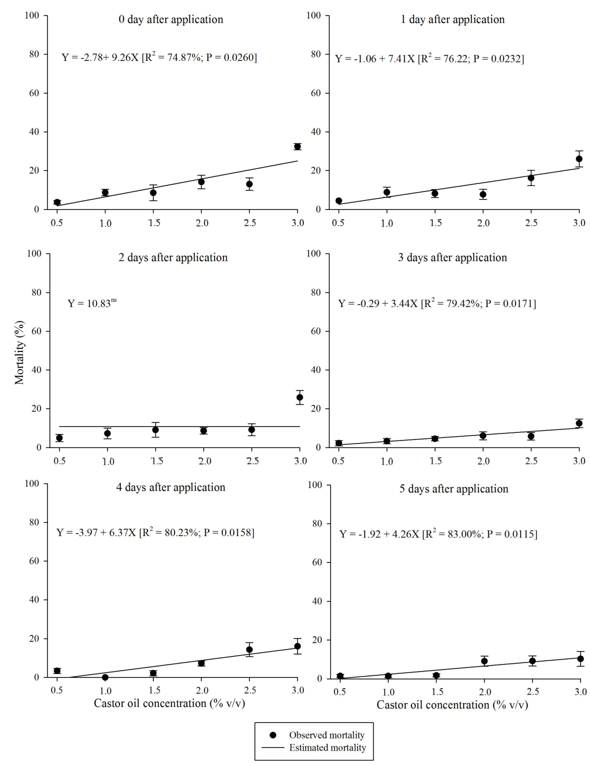

Figure 2. Effects of residual castor oil on the mortality of the coffee berry borer with days after application as a function of the concentration. The experiment was conducted at 25±1°C, a RH of 60±10% and a photoperiod of 12:12 hours light: dark.

The coffee berry borer mortality caused by the residual castor oil at the concentrations of 0.5, 2.0 and 2.5% (v v^{-1}), which was not adjusted to any model, remained constant over time (Figure 3). The constant mortality with time was associated with the low mortality caused by these castor oil concentrations and also with the similar values until the 5th day after application. However, for mortality of the coffee berry borers at the concentrations of 1.0, 1.5 and 3.0% (v v^{-1}), which was adjusted to the linear model, there was a reduction in the mortality as a function of time (Figure 3). In this case, it was notable that the initial mortality for the concentrations of 1.0 and 1.5% (v v^{-1}) was low, unlike for the concentration of 3.0% (v v^{-1}) of castor oil, which had a higher initial value of mortality for the coffee berry borers.

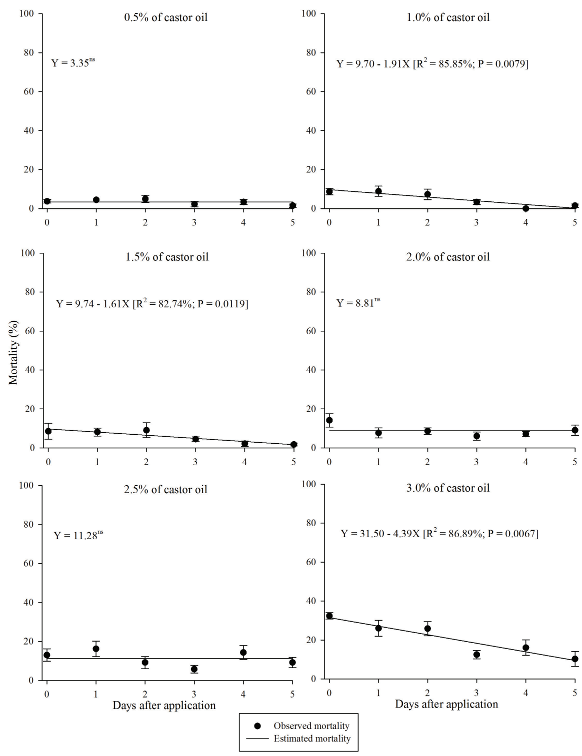

Figure 3. Effect of residual castor oil on the mortality of the coffee berry borer with concentration as a function of days after application. The experiment was conducted at 25±1°C, a RH of 60±10% and a photoperiod of 12:12 hours light:dark.

As in the present work, the residual effects of castor oil resulted in a significant decrease in the larval mortality of *P. xylostella* during the time between the application and the release of insects (Tounou et al., 2011). This result might be related to the low persistence of castor oil, which requires further research to improve the persistence. When a botanical insecticide is exposed to the elements, such as light, temperature and air, the insecticide is quickly degraded and becomes unstable in the environment (Gangwar, 2012; Radwan & El-Shiekh, 2012; Turek & Stintzing, 2013) because of the removal of the chemical compound protection compartment in the plant. Additionally, the insecticides are affected by destructive extraction methods, which cause oxidative damage and chemical and/or polymerization reactions (Miresmailli & Isman, 2014). Thus, aged plant extracts tend to lose the quality of some of the attributes, including odour, flavour, colour and consistency (Turek & Stintzing, 2013). The diversity in the composition of the botanical extracts and the instability of the constituents might make some of these botanicals unsuitable for application, particularly when residual effects are desired for long periods of time (Gahukar, 2014; Miresmailli & Isman, 2014).

Understanding the persistence of botanical insecticides in the environment is extremely important, because the coffee berry borers remain within the coffee fruit for nearly the entire life cycle, in addition to a cryptic habit; thus, this pest is difficult to control (Vega et al., 2009). Therefore, the insecticides must reach this pest from September to December, because during this period, the coffee berry borer females leave the fruit to search for food (the female transit period). Therefore, studies on the effects of botanical insecticide residuals are an important factor for success in the management of this pest with plant-derived products.

Conclusion

The primary component of castor oil is ricinoleic acid. The insecticide that contained azadirachtin (ICA) and the castor oil caused mortality of 40.8 and 53.7% of the coffee berry borers, respectively. The castor seed cake extract was not toxic to *H. hampei* at a concentration of 3.0% (w v^{-1}). Moreover, the castor oil had low persistence in the environment, which complicated the control of the coffee berry borers.

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