Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Increased capture efficiency of Scolytinae with modified semi-funnel trap model

Aumento da eficiência de captura de Scolytinae com armadilha modelo semifunil modificada

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Abstract

Scolytinae species that, in high populations, can damage reducing wood production in forest crops. These beetles are monitored with traps baited with ethanol and increasing their efficiency can improve the integrated management of these insects. The objective was to evaluate the increase in the capture efficiency of Scolytinae with a semi-funnel trap model, in two experiments, one including wooden elements and other increasing the flight interception area and to correlate the numbers of these beetles collected with climatic factors. In the experiment 1, *Eucalyptus urophylla* S. T. Blake slats were directly attached to the collector flask and in another treatment, in addition to these slats, *Cedrela* sp. strips were inserted inside the bait holding hose. In the experiment 2, the insect interception area in the trap, originally 480 cm^2, was expanded to 1,200 cm^2 and compared with the model Pet–Santa Maria trap with an interception area of 550 cm^2. Weekly collections were carried out between May 2018 and June 2019. The beetles collected were taken to the Wood Biodeterioration Laboratory of the Federal Rural University of Rio de Janeiro (UFRRJ) where they were sorted, identified at family level, counted and their number correlated with climatic factors. Statistical analyzes of the collected data were processed by the BioStat® 5.3 program. In the experiment 1 were collected 869 Scolytinae. The numbers of beetles collected per trap without modification, with *E. urophylla* slats and *E. urophylla* slats + *Cedrela* sp. strips were similar, 7.3 ± 3.8, 7.8 ± 6.2 and 7.7 ± 5.0 respectively. In the experiment 2 were collected 4,398 Scolytinae. Increasing the interception area of the beetles increased the efficiency of the semi-funnel trap, with 42.7 ± 20.5 Scolytinae collected compared to the original semi-funnel trap, 28.6 ± 12.6 and the Pet–Santa Maria, 20.4 ± 10.4, per trap. The number of Scolytinae did not correlate with climatic factors in the experiment 1 and it was correlated with temperature, relative humidity and wind speed, but not with precipitation, in the 2. The incorporation of *E. urophylla* slats or *Cedrela* sp. strips in the semi-funnel trap did not increase the number of beetles collected, but, the increase in the flight interception area and the temperature, relative humidity and wind speed were correlated with the number of beetles collected.

Keywords: climatic factors, ethanol baited traps, interception area, population monitoring.

Resumo

Espécies de besouros Scolytinae, em altas populações, podem danificar a madeira e reduzir a produtividade de cultivos florestais. Esses besouros são monitorados com armadilhas iscadas com etanol e o aumento da eficiência das mesmas pode melhorar o manejo integrado desses insetos. O objetivo foi avaliar o aumento da eficiência de captura de Scolytinae com armadilha modelo semifunil, em dois experimentos, um incluindo elementos de madeira e outro aumentando a área de interceptação de voo e correlacionar o número desses besouros coletados com fatores climáticos. No experimento 1, ripas de *Eucalyptus urophylla* S. T. Blake foram fixadas, diretamente, no frasco coletor e em outro tratamento, além dessas ripas, fitas de *Cedrela* sp. foram inseridas no interior da mangueira porta isca. No experimento 2, a área de interceptação de insetos na armadilha, originalmente, com 480 cm^2, foi ampliada para 1200 cm^2 e comparada com a armadilha modelo Pet–Santa Maria com área de interceptação de 550 cm^2. Coletas semanais foram realizadas entre maio de 2018 a junho de 2019. Os insetos capturados foram levados ao Laboratório de Biodeterioração da Madeira da Universidade Federal Rural do Rio de Janeiro (UFRRJ) onde foram triados, identificados em nível de família, contados e a abundância correlacionada com fatores climáticos. As análises estatísticas dos dados coletados foram processadas pelo programa BioStat® 5.3. No experimento 1 foram coletados

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Received: December 13, 2021 – Accepted: May 10, 2022

869 Scolytinae. Os números de besouros coletados por armadilha sem modificação, com ripas de *E. urophylla* e com ripas de *E. urophylla* + fita de *Cedrela* sp. foram semelhantes, 7,3 ± 3,8; 7,8 ± 6,2 e 7,7 ± 5,0 respectivamente. No experimento 2 foram coletados 4398 Scolytinae. O aumento da área de interceptação dos besouros aumentou a eficiência da armadilha semifunil, com 42,7 ± 20,5 Scolytinae coletados por armadilha comparado a semifunil original, 28,6 ± 12,6 e a Pet–Santa Maria, 20,4 ± 10,4. O número de Scolytinae não se correlacionou com os fatores climáticos no experimento 1 e se correlacionou com a temperatura, umidade relativa e velocidade do vento, mas não com a precipitação, no 2. A incorporação de ripas de *E. urophylla* ou fitas de *Cedrela* sp. na armadilha semifunil não aumentou o número de besouros coletados, mas, o aumento da área de intercepção de voo e a temperatura, umidade relativa do ar e velocidade do vento se correlacionaram com o número de besouros coletados.

Palavras-chave: área de interceptação; armadilhas iscadas com etanol; fatores climáticos; monitoramento populacional.

1. Introduction

Scolytinae species, in high populations, are pests and can damage trees reducing wood production and increasing fire risks (Li and Li, 2019). Besides, Scolytinae can be vectors of phytopathogenic fungi (Chakraborty et al., 2020; Contarini et al., 2020) causing tree death and some species can transmit viruses (Oliveira et al., 2021). These beetles identify suitable host plants for colonization by detecting semiochemicals released by those physiologically stressed (Özcan et al., 2018; Zhao et al., 2020) or recently dead or dying (Aflitto et al., 2015).

Monitoring of Scolytinae with pheromone-baited traps (Galko et al., 2016) or ethanol (Oliveira et al., 2017; Skrzecz et al., 2019) determines population density to assist in the integrated management of these forest pests (Carvalho and Trevisan, 2015; Borkowski, 2017). The fermentation of extractives from newly cut wood forms this compound (Lemos et al., 2020; González–Peñas et al., 2020) indicating plants suitable for colonization by Scolytinae and, therefore, used in traps to attract these beetles (Klingeman et al., 2017).

The cost of traps, such as the Lindgren funnel or the reed panel, is high (Steininger et al., 2015), making it necessary to develop simpler, cheaper and efficient models, such as those made with recycled materials (Murari et al., 2012; Steininger et al., 2015; Carvalho and Trevisan, 2015). Strategies to improving and managing traps in the field can increase the efficiency of capturing wood borers (Trevisan et al., 2021).

The objective was to evaluate the capture efficiency of Scolytinae using a semi-funnel trap model, including the incorporation of *Eucalyptus urophylla* S. T. Blake slats and *Cedrela* sp strips and the increase the insect interception area and to correlate the number of these beetles collected with climatic factors.

2. Material and Methods

2.1. Experimental area

The experiments were carried out in a secondary forest fragment of the Atlantic Forest with an area of 3.5 ha in the campus of the Federal Rural University of Rio de Janeiro (UFRRJ) in Seropédica, Rio de Janeiro, Brazil (22°44'38"S, 43°42'27"W, 26 m). The region climate is Aw, according to Köppen's classification, with annual rainfall of 1,213 mm concentrated from November to March and average annual temperature of 23.9 ºC (Silva et al., 2016).

2.2. Sampling

The Scolytinae were collected with six semi-funnel model traps, suspended randomly in the area at approximately 1.30 m high and 20 m apart from each other. These traps were made with polyethylene bottles (PET) of two liters and 500 g bottles (collector pot) baited with 96% ethanol and a 5 mm diameter hose, where 96% ethanol was placed with the aid of a 20 mL syringe (Carvalho and Trevisan, 2015).

Two experiments were conducted. One using *E. urophylla* slats and *Cedrela* sp. strips were placed in the semi-funnel trap to increase the ethanol volatilization (experiment 1) and in the other, the insect flight intercept area was increased with the incorporation of an extra panel in the trap (experiment 2). The number of traps adopted was based on the methodology proposed by Trevisan et al. (2021).

In the experiment 1, two traps were used per treatment, being: 1) unmodified semi-funnel trap (control) (Carvalho and Trevisan, 2015); 2) semi-funnel trap with two *E. urophylla* slats (30 cm long × 10 cm wide × 2.5 cm thick) in the collector pot; and 3) traps with two *E. urophylla* slats and one *Cedrela* sp. strip (50 cm long × 3 cm wide x 0.5 mm thick) inside the ethanol hose. The incorporation of wooden elements in the traps aims to increase the volatilization of alcohol in the environment, as this material is hygroscopic and, theoretically, would work as a diffuser of this volatile (Figure 1).

In the experiment 2, two traps were used per treatment, and the conditions in the were: 1) unmodified semi-funnel trap (480 cm^2 of interception area); 2) semi-funnel trap with an extra panel (1,200 cm^2 of total interception area); and 3) model Pet–Santa Maria trap (550 cm^2 of interception area) (Murari et al., 2012). The inclusion of an extra panel in the semi-funnel trap increased the insect interception area and the Pet-Santa Maria, flat trap, served for comparison because its interception area is intermediary in relation to the others (Figure 2).

2.3. Collections

The insects were collected weekly from May to September 2018 (experiment 1 with 19 collections) and from December 2018 to June 2019 (experiment 2 with 28 collections), when the ethanol from the collector pots and the hose was replenished. The insects collected were taken to the Wood Biodeterioration Laboratory of the Forestry Products Department of the Forests Institute/UFRRJ and screened and counted.

The averages of temperature, precipitation, relative humidity and wind speed were obtained from the

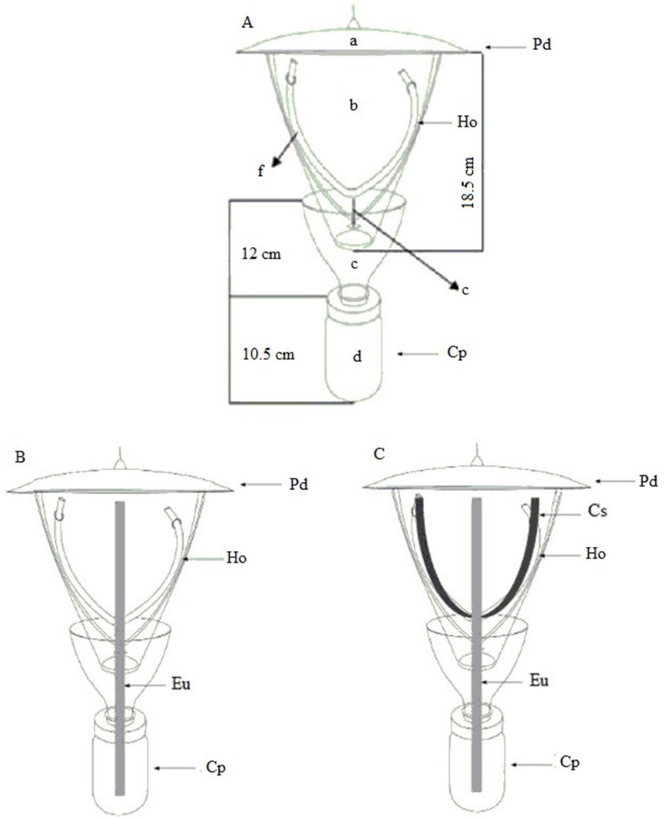

Figure 1. Original semi-funnel model trap (A) in front view with protective plate (a), "semi-funnel" interceptor panel (b), collecting funnel (c), storage bottle (d), fixing wire (e) and bait holding hose (f); (A) with *Eucalyptus urophylla* slats (B) and *Eucalyptus urophylla* slats and *Cedrela* sp. strip (C). Pd= Plastic dish to protect the collecting pot from rainwater; Ho= Hose to adding ethanol; Cp= Collecting pot baited with ethanol; Eu= *Eucalyptus urophylla* slat and Cs= *Cedrela* sp. strip.

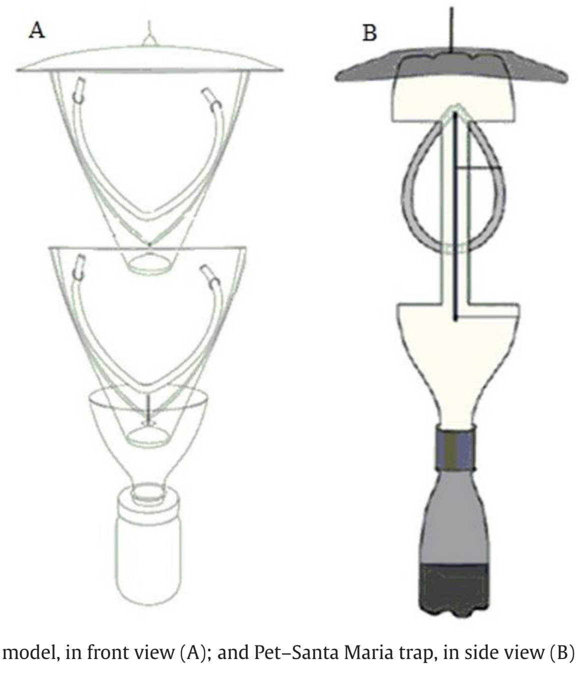

Figure 2. Modified semi-funnel model, in front view (A); and Pet–Santa Maria trap, in side view (B) (Source: Murari et al., 2012).

Meteorological Station of the National Institute of Meteorology (Agricultural Ecology) located in the Ecology district in Seropédica, Rio de Janeiro, Brazil (22º45'28"S; 43º41' 05"W, 35 m) (INMET, 2019).

2.4. Statistical analysis

Data were processed with the BioStat® 5.3 program (Ayres et al., 2007) and their normality assessed by the Lilliefors method ($p < 0.05$). The total numbers of Scolytinae collected were given by the absolute frequency of these individuals in relation to the total number of other insect group captured in the traps. The numbers of Scolytinae were submitted to the Kruskal–Wallis test ($p < 0.05$) and the mean numbers analyzed by the Dunn test ($p < 0.05$). These numbers and climatic factors were analyzed by Pearson correlation. This correlation was interpreted by criteria considering the correlation expressed by R values between 0.10 and 0.29 as low; average between 0.30 and 0.49; and high between 0.50 and 1.0 (Cohen, 1977).

3. Results

Experiment 1: Semi-funnel model trap with wooden elements

A total of 869 Scolytinae beetles were collected in all traps, with similar values between the traps with *E. urophylla* slat (Eu), *E. urophylla* slat and *Cedrela* sp. strip, and in the control (Table 1).

Experiment 2: Extension of the trap insect interception area

A total of 4,398 Scolytinae beetles were collected in the traps. The number of individuals of this subfamily captured was higher with the modified semi-funnel (1200 cm^2), followed by the original semi-funnel (480 cm^2) and the Pet–Santa Maria (550 cm^2) traps (Table 2).

3.1. Influence of climate factors

The number of Scolytinae captured was higher in January 2019 (324 beetles), the month with the highest temperature and lowest precipitation. The variation in the average temperature, relative humidity and wind speed was low, but precipitation during the collection period varied (Figure 3).

The number of individuals of Scolytinae did not correlate with the climatic factors temperature, relative humidity, wind speed and precipitation in the experiment 1, but it correlated with temperature, relative humidity and wind speed, but not with precipitation in the 2 (Table 3).

Table 1. Total number (absolute frequency – Af), average ± standard deviation and range of variation (maximum and minimum) of Scolytinae data captured in ethanol traps without (control) and with *Eucalyptus urophylla* slat (Eu) and *E. urophylla* slat and *Cedrela* sp. strip (Eu + Cs) in a secondary forest fragment of the Atlantic Forest, Seropédica, Rio de Janeiro, Brazil.

Traps	Af	Average ± standard deviation *	Maximum	Minimum
Control	277	7.3 ± 3.8a	11.1	3.5
With Eu	298	7.8 ± 6.2a	14.0	1.6
With Eu + Cs	294	7.7 ± 5.0a	12.7	2.7

*Average followed by the same letter, per column, do not differ by Dunn's Test ($p < 0.05$).

Table 2. Total number (absolute frequency – Fa), average ± standard deviation and data variation range (maximum and minimum) of Scolytinae captured in the semi-funnel, modified semi-funnel and Pet–Santa Maria traps in a secondary forest fragment of Atlantic Forest, Seropédica, Rio de Janeiro Brazil.

Traps	Af	Average ± standard deviation *	Maximum	Minimum
Semi-funnel	1,376	28.6 ± 12.6 b	41.2	16
Modified semi-funnel	2,011	42.7 ± 20.5 a	63.2	22.2
Pet–Santa Maria	1,011	20.4 ± 10.4 c	30.8	10

*Average followed by the same letter, per column, do not differ by Dunn's Test ($p < 0.05$).

Table 3. Pearson correlation coefficients between the number of Scolytinae collected in experiment 1 (ethanol traps with or without *Eucalyptus urophylla* slat and *Cedrela* spp. strip) and 2 (semi-funnel, modified semi-funnel and Pet–Santa Maria ethanol traps) and climatic factors (temperature, precipitation, relative humidity and wind speed) in secondary forest fragments of the Atlantic Forest and four climatic variables. Seropédica, Rio de Janeiro, Brazil.

Climatic factors	Experiment 1			Experiment 2		
	P	***R***	**Correlation**	***P***	***R***	**Correlation**
Temperature (ºC)	0.9868	0.0041	Low	0.0232	0.4276	Average
Precipitation (mm)	0.7510	–0.0780	Low	0.5797	–0.1093	Low
Relative humidity (%)	0.7449	–0.0800	Low	0.0182	–0.4428	Average
Wind speed (m/s)	0.3249	–0.2388	Low	0.0065	0.5020	High

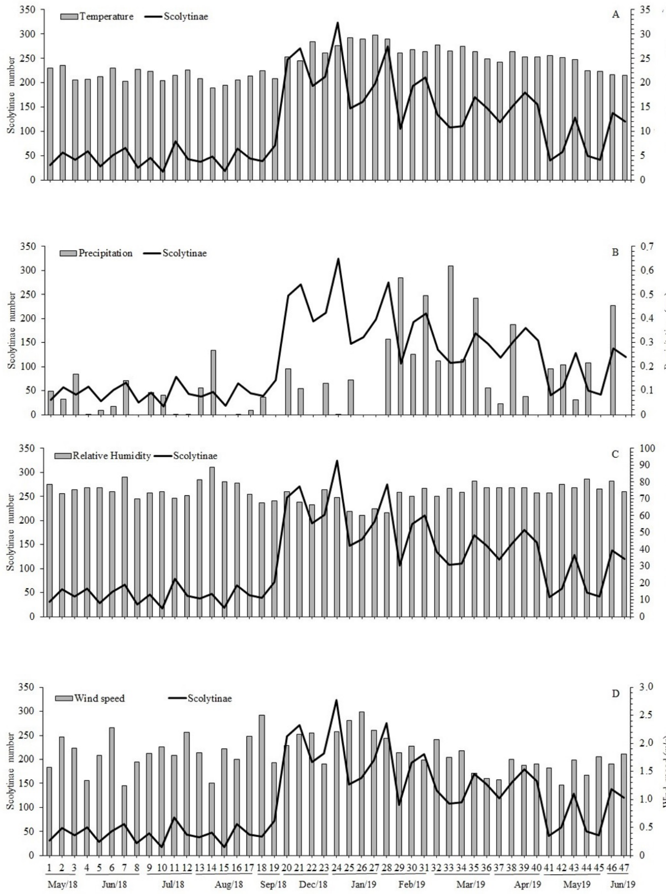

Figure 3. Number of Scolytinae collected and average temperature (ºC) (A), precipitation (mm) (B), relative humidity (%) (C) and wind speed (m/s) (D) in a secondary forest fragment from Atlantic Forest, Seropédica, Rio de Janeiro, Brazil from May 2018 to June 2019.

4. Discussion

Experiment 1: Semi-funnel model trap with wooden elements

The similar number of individuals of Scolytinae between treatments with the semi-funnel traps indicates that the wooden slats or strips did not increase alcohol volatilization. This could be due to the material used being dry and with humidity in balance with the environment and, therefore, without extractive fermentation, differing from the green material (Yang and Liu, 2020) and without the absorption and greater release of alcohol. On the other hand, compounds from green wood ferment after the tree harvest (Routa et al., 2020), attracting Scolytinae due to alcohol production (Lemos et al., 2020). These beetles are attracted to different alcohol types, including methanol and ethanol, 95% ethyl alcohol, P.A. isopropyl alcohol and methyl alcohol (Matos et al., 2019). Furthermore, the color of the traps affect the collection of Scolytinae, as the number of individuals of the coffee borer, *Hypothenemus hampei* Ferrari, 1867 (Coleoptera: Curculionidae: Scolytinae) was higher in traps made with a red PET bottle baited with a mixture of ethanol and methanol (1:1 ratio) + benzoic acid than in those with a combination of other volatile mixtures with parts of ethanol, methanol, benzaldehyde and benzoic acid painted in colors green and red + green (Souza et al., 2020). *Hypothenemus hampei* is firstly attracted by the secondary metabolites produced by coffee during the fruit formation and then by the color and shape of this fruit (Leiva-Espinoza et al., 2019). Therefore, the red color of the traps is more attractive as it resembles that of the coffee fruit stage in development (Souza et al., 2020).

The number of individuals of Scolytinae was similar to that obtained in *Eucalyptus camaldulensis* Dehnh plantations in Cuiabá, Mato Grosso state, Brazil (Rocha et al., 2011a). The high number of individuals of Scolytinae captured in traps is due to their attraction to ethanol (Klingeman et al., 2017; Byers et al., 2020). The efficiency of collecting Scolytinae with ethanol (Kamata et al., 2020), a compound released during the fermentation of extractives in stressed or newly harvested trees, is due to the use of this compound by these insects to locate suitable trees for colonization (González-Peñas et al., 2020; Soares Gusmão et al., 2020; Zhao et al., 2020).

Experiment 2: Extension of the trap insect interception area

The greatest number of Scolytinae individuals, collected with the semi-funnel trap (1,200 cm^2), agrees with report of greater efficiency of window (4,284 cm^2) and cross-barrier (5,500 cm^2) traps than those with multiple funnels (3,863 cm^2) with smaller interception areas (Chen et al., 2010). The lowest number of Scolytinae captured with the Pet–Santa Maria trap, the second with the largest interception area (550 cm^2), differs from the theory of greater efficiency of flat traps to capture these insects than cross or cylindrical traps, due to the higher ratio between the effective interception area and the trap surface (Safranyik et al., 2004; Allison and Redak, 2017). The insect flight angle in relation to the impact surface affects the capture of Scolytinae, as an insect flying parallel to the flat panel of the trap will not be captured due to an angle equal to or close to 0º (Safranyik et al., 2004). This may explain differences between the results of the original and the modified semi-funnel traps, both with angled panels compared to the Pet–Santa Maria.

The greater number of Scolytinae captured in the semi-funnel trap than in the Pet–Santa Maria agrees with report for wood borers collected with these traps and also with the Marques–Pedrosa and Carvalho–47 types in an agroforestry corridor in the municipality of Seropédica, Rio de Janeiro, Brazil (Bossoes, 2011). The cost of the Pet–Santa Maria trap is lower and it is more practical than the Marques–Pedrosa, Escolitídeo–Curitiba, Marques–Carrano and Roechling traps, but these first two were more efficient in capturing Scolytidae in native forest in the municipality of Itaara, Rio Grande do Sul, Brazil (Pelentir, 2007). The relationship between the distance where the insect starts its flight to the trap and the proportion of individuals captured among those attracted also affect the success of capturing them in the traps (Allison and Redak, 2017).

4.1. Influence of climate factors

The largest number of individuals of Scolytinae in drier and warmer months, differs from that reported for *Cryptocarenus diadematus* Eggers, 1937 and *Cryptocarenus heveae* Hagedorn, 1912 (Coleoptera: Curculionidae: Scolytinae) with higher numbers in the rainier periods in *Eucalyptus urophylla* x *Eucalyptus grandis* W. Hill ex Maiden plantation in Alta Floresta, Mato Grosso state, Brazil (Monteiro et al., 2018). The precipitation in this region is very high, which may have induced these beetles to start flying in the rainy season (Monteiro et al., 2018). The relative humidity variation was low with an average of 74.20%, during the collections of the largest number of individuals in the months of December and January, when the relative humidity was 67.75%, 8.7% lower than the average recorded during the experiment. However, *C. diadematus* was more collected in periods with lower relative humidity in *Eucalyptus urophylla* x *Eucalyptus grandis* plantations in Mato Grosso state, Brazil (Martins e Silva et al., 2021). The average wind speed, during the experiment was 1.82 m/s to 2.17 m/s in the months with the highest Scolytinae collection. Generally, wind speed is inversely correlated with the collection of these insects, but they can fly in the presence or absence of wind (Wijerathna and Evenden, 2020). Climatic variations influence plant development, directly affecting the diversity and number of Scolytinae due to the associations between these beetles and their host plants (Cajaiba et al., 2018).

The lack of correlation between the number of Scolytinae captured and the temperature in the experiment 1 and precipitation in both experiments is similar to that reported for *Crypturgus* spp., *Dryocoetes autographus* Ratzeburg, 1897, *Hylurgops palliatus* Gyll, 1813, *Orthotomicus* spp. and *Pityophthorus pityographus* Ratzeburg, 1897 (Coleoptera: Curculionidae: Scolytinae) in wild pine forests in alpine valleys of Central Europe (Wermelinger et al., 2021). The positive mean correlation between the number of Scolytinae collected and the temperature in the experiment 2 is similar to that reported for *Xyleborus affinis* Eichhoff, 1868 (Coleoptera: Curculionidae: Scolytinae) in periods with warmer temperatures in Santa Cruz, Rio de Janeiro state, Brazil (Silva et al., 2020).

The negative correlation, in the experiment 1 and 2 between the number of Scolytinae collected and the precipitation corroborates that reported for *X. affinis* in a preserved fragment of savannah in Coxipó-da-Ponte, Cuiabá, Mato Grosso, Brazil (Goulart et al., 2018). High rainfall can reduce alcohol volatilization and, consequently, Scolytinae flight (Sanguansub et al., 2020). The increase in the temperature and precipitation improve the quality of the host tree phloem and the positive or negative correlation of these factors with the number of Scolytinae captured varies with the evolutionary success of these beetles, the host tree and its monoterpene contents (Wermelinger et al., 2021).

The low and negative correlation, in the experiment 1, and medium, in the 2, of the number of Scolytinae captured with the relative humidity of the air agrees with that reported for *C. diadematus*, *Cryptocarenus seriatus* Eggers, 1933 and *Hypothenemus obscurus* Fabricius, 1801 (Coleoptera: Curculionidae: Scolytinae) in *Eucalyptus* spp. plantations in Cuiabá, Mato Grosso state, Brazil (Dorval et al., 2004). On the other hand, it differs from that reported for *Coptoborus ochromactonus*, n. sp. (Coleoptera: Curculionidae: Scolytinae) with higher numbers of individuals collected in commercial plantations of *Ochroma pyramidale* (Cav. Ex. Lam.) Urb. with increasing relative humidity in Ecuador (Martínez et al., 2020). High temperature and humidity improve the growth of symbiotic fungi on their host plants and, consequently, of Scolytinae populations (Atkinson, 2019).

The low and negative correlation between the number of Scolytinae captured and the wind speed, in the experiment 1, can be explained by the reduced variation in this parameter during the period of collection of these insects (Martínez et al., 2020). On the other hand, the high and positive correlation in the experiment 2 was expected as this variable increases the dispersion of attractive substances and, consequently, the attraction of Scolytinae (Salom and McLean 1991; Wijerathna and Evenden, 2020). The influence of environmental variables depends on Scolytinae species and where these insects are collected (Rocha et al., 2011a, b). Environmental factors, in addition to tree health, wood density, moisture content in the host tissue and vegetation composition affect the collection of these insects (Martínez et al., 2019).

Implementing strategies to increase the capture efficiency of Scolytinae from traps made with recyclable materials are extremely important for population monitoring of these insect pests. Thus, the results of this work show, in practice, that the use of wooden elements in the traps does not significantly affect the capture efficiency of Scolytinae. On the other hand, expanding the insect interception area provides an efficient strategy to optimize the capture of Scolytinae beetles. Therefore, the results presented in this work demonstrate that the population monitoring of Scolytinae can be improved using traps with larger insect interception areas, especially in the semi-funnel trap model.

5. Conclusions

The incorporation of *E. urophylla* slats and *Cedrela* sp. in the semi-funnel trap model did not increase the number of Scolytinae captured. The expansion of the insect interception area, with an extra panel, increased the number of these beetles captured in the semi-funnel trap model. The number of beetles collected was positively correlated with temperature and wind speed and negatively with relative air humidity in the experiment 2 with the increasing of insect flight intercept area in the semi-funnel trap.

Acknowledgements

To “Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)”, “Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES- Finance Code 001), “Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG)” and “Programa Cooperativo sobre Proteção Florestal (PROTEF) do Instituto de Pesquisas e Estudos Florestais (IPEF)” for financial support.

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