Research Article

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Successful management of *Stegasta bosqueella* (Lepidoptera Gelechiidae) in peanut with an attract-and-kill strategy

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Abstract

BACKGROUND: Rednecked Peanutworm *Stegasta bosqueella* control is primarily achieved using broad spectrum insecticides targeting the larval stage. However, due to inconspicuous behavior and limited movement of the larvae within the peanut crop, foliar insecticides alone have been insufficient to reduce *S. bosqueella* populations. The poor effectiveness of chemical products, combined with the necessity of frequent fungicide applications, leads to an overuse of pesticides in peanuts. Given the challenges associated with targeting the larval stage, alternative strategies are needed to improve pest management. Our hypothesis was that by targeting the adult stage, the most mobile stage of the insect, we could decrease the levels of *S. bosqueella* damage in peanut crops while being less aggressive to the environment.

RESULTS: Over 2 years, our study demonstrated that semiochemical-food-based attract and kill treatments significantly reduced the number of *S. bosqueella* adults captured per food-baited trap per week. This reduction was associated with fewer larvae and decreased plant damage compared to untreated control areas. To optimize this strategy, several key practices must be followed: (a) Prompt treatment application (chemical associated with attractant) should be applied upon detection of an increase in adult trap catches; (b) Timing applications to coincide with peak adult movement (6 pm to 9 pm); and (c) Applying treatments strategically on two peanut rows, 50 m apart, per hectare.

CONCLUSIONS: The attract-and-kill method can effectively reduce *S. bosqueella* damage in peanut crops, and has the potential to target other moth species that act as peanut defoliators.

Supporting information may be found in the online version of this article.

Keywords: semiochemicals; peanut integrated pest management; behavioral manipulation; attractant food; spatial and temporal distribution

1 INTRODUCTION

Substances that allow insect behavior manipulation such as semiochemicals and the investigation of their potential for pest management and control of invasive species has been widely studied.[1–4] Semiochemicals are chemical substances that mediate interactions between organisms, within the same (pheromones) or different (allelochemicals) species. Due to their specialized mode of action on the target insect species, this strategy is less aggressive to the environment and has been used in the context of integrated pest management (IPM) in mass capture and mating disruption[5,6] or in combination with insecticides or pathogens in a strategy called 'Attract-and-Kill'.[3]

The Rednecked Peanutworm (RP), *Stegasta bosqueella* (Lepidoptera: Gelechiidae), with its cryptic behavior and status as a key insect pest of peanut crops (*Arachis hypogaea* L.), has been a limiting factor for sustainable peanut production in the Americas.[7,8] Lepidopteran control in peanuts primarily relies on successive applications of foliar insecticides,[9–11] accounting for 10–11% of production costs.[12] However, the sole reliance on chemical intervention for managing lepidopteran pests in peanuts has been shown to have limited effectiveness due to the low mobility and inconspicuous behavior of the larval phase, which resides inside closed new peanut leaflets.[8,13] Therefore, by targeting the highly mobile adult stage with attract-and-kill methods, we can achieve two key benefits: first, control occurs before the insect damages crops, and second, the specificity to adults inherent in the technique can potentially enhance the presence of beneficial biological control agents in the field, due to restriction of contact between a toxicant and beneficial organisms in comparison to broadcast spraying.

Attract-and-kill strategy has been efficient in controlling important agricultural pests of different taxa such as the Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae),[14] Western Corn

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Rootworm *Diabrotica virgifera* (Coleptera: Chrysomelidae),[15] Codling Moth *Cydia pomonella* (Lepidoptera: Tortricidae)[16] as well as invasive species such as brown marmorated stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae)[17] and spotted-wing drosophila *Drosophila suzukii* (Diptera: Drosophilidae).[18] This strategy combines an attractive semiochemical with a mortality agent and can be applied either associated with a capture device or also used in a formulation for direct application (spraying). Thus, its adoption leads to reduced amounts of pesticides used, decreased contact of chemicals with the environment, which benefits the action of beneficial organisms, and lower production costs, which consequently increases the profitability of crops.[19]

Most products for attracting adult insects are based on pheromones, particularly sex pheromone. However, pheromones are highly specific, typically attracting males exclusively. Since commercial pheromones are not yet available for *S. bosqueella*, we explored using a food attractant based on a combination of attractive plant volatiles and sugars. Food attractants target both males and females. Therefore, we hypothesized that we can significantly reduce the number of individuals in subsequent generations with this attract-and-kill strategy. This is because eliminating males from the population also diminishes the reproductive potential of females.[20]

To evaluate the potential of attract-and-kill for *S. bosqueella* control in peanuts, we conducted field trials across two cropping seasons in commercial peanut areas. These trials aimed to identify both the peak abundance period of the pest during the growing cycle and the optimal timing and application protocol for the attractant food spray. Additionally, we aimed to determine the effective attraction distance for adult *S. bosqueella* through studies of spatial and temporal distribution, which could further increase mortality rates in the field by maximizing adult attraction to the sprayed formulation. Such a study, to our knowledge, has not been conducted before to recommend the attract-and-kill strategy for other crops.

2 MATERIALS AND METHODS

2.1 Experimental site

We conducted field trials in commercial peanut areas of São Paulo State, Brazil during the 2017/2018 and 2019/2020 growing seasons. The IAC 503 peanut cultivar, a runner variety with high oleic acid content (70–80% in the oil) was used in both seasons.[21] The standard row spacing was 0.90 cm, with 18 seeds sown per meter, resulting in a final plant population of approximately 130 000 plants per ha. Standard agricultural practices recommended for peanut cultivation were adopted.[22] Larvicide applications were excluded from the trials, but insecticide applications of thiamethoxan (Actara 250 WG®, Syngenta) and imidacloprid (Imidagold 700 WG®, UPL) were used to control *Enneothrips enigmaticus* (Thysanoptera: Thripidae), a highly abundant insect pest in Brazilian peanuts.[23] These products were chosen because they have less effect on lepidopterous defoliators.[24]

2.2 Experimental design

2.2.1 First season

The experiment was conducted from November 2017 to March 2018 in a 6-ha experimental area within a commercial peanut producing farm at Taquaritinga municipality, Brazil (21.43016893S −48.60981799 W). Over this period, 27 samples (individual site visits for sampling adults, larvae and injury evaluation) were conducted. The average maximum and minimum temperatures, relative humidity and accumulated precipitation during the study period were 28.7 °C, 19.5 °C, 85% and 965 mm, respectively (see Supplementary S1 for details). A randomized block design was employed, with two treatments and three replications: (1) application of attract-and-kill and (2) control (without application) (Fig. 1). For each treatment, a 1-ha plot (100 m by 100 m) spaced 50 m apart from each other was adopted. Blocks were spaced 250 m apart and the surrounding areas consisted of commercial sugarcane plantations.

2.2.2 Second season

Similar to the previous season, the experiment was conducted from November 2019 to February 2020, collecting a total of 25 samples (individual site visits for sampling adults, larvae and injury evaluation) in an 8-ha experimental area. The experimental site was established in a commercial farm at Santa Ernestina municipality, Brazil (21.49048298S, −48.38833998 W). The average maximum and minimum temperature, relative humidity (%) and accumulated precipitation (mm) during the study period were 29.5 °C, 20.5 °C, 78%, and 799 mm, respectively (see Supplementary S2 for details). A randomized block design with four replicates was used, following the same two treatments described previously (Fig. 1). Each plot consisted of an area of approximately 1 ha. Plots were spaced 50 m apart, and blocks were spaced 100 m apart.

2.3 Application of the attract-and-kill formulation

To apply the attract-and-kill treatment, we used the commercially available food attractant for moths, Noctovi/Acttra Noctuideo® (Isca Technologies TM). This product is a blend of plant volatiles (linalyl alcohol 0.42%) and sugars (sucrose 19.25% and invertose 4.81%) suitable for monitoring and direct application when combined with an insecticide. The attract-and-kill formulation was applied following the manufacturer's instructions for application using a backpack sprayer. It consisted of a combination of Noctovi/Acttra Noctuideo® with the methomyl active ingredient (Bazuka®, Rotam Brazil, Campinas, São Paulo, Brazil or Lannate®, Corteva, Indianapolis, Indiana, USA) at a 4% concentration per spray rate volume. The final volume applied was 1 L per ha.

Applications were consistently performed after 5 pm using a 5-L backpack sprayer equipped with a DCC 3 large nozzle (Jacto S.A.®, Pompéia, São Paulo, Brazil). For both seasons, applications were initiated upon finding an average of 10 or more adults per trap in at least two consecutive monitoring sessions. This threshold was empirically established because there is no research combining adult catches and larval infestation of the Rednecked Peanutworm. In the 2017/2018 season, a single strip of attractant was applied in the center of each plot, whereas in the 2019/2020 season, two strips spaced 50 m apart were applied. The total volume used remained the same as in the first season by adopting intermittent spraying, where the nozzles were turned on and off every 1.5 m.

2.4 Sampling

2.4.1 Adults

For adult moth sampling, one Ajar® delta trap (with adhesive floors) and one ISCA Ball Trap® (plastic bowls with funnels and collection bags) containing Noctovi/Acttra Noctuideo® as an attractant were used during the 2017/2018 season (Isca Technologies™, Riverside, CA, USA). In the 2019/2020 season, only one Ajar® delta trap was used for adult sampling, as it was effective in attracting adults and offered two key advantages: ease of

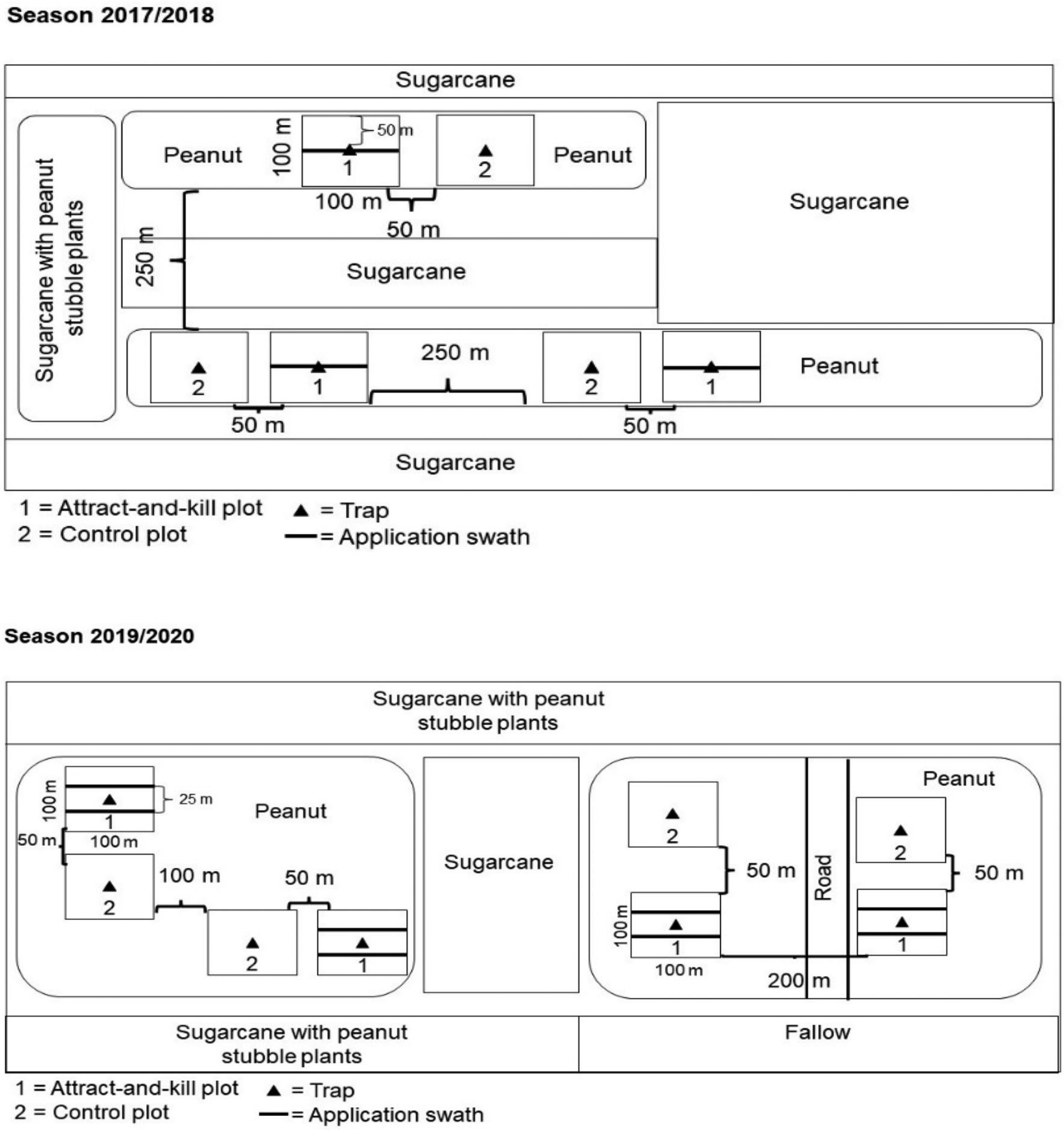

Figure 1. Sketch of plot distribution in the 2017/2018 field trial (A) and 2019/2020 field trial (B) where plots 1 = Attract-and-Kill and plots 2 = Control.

handling and sorting of collected insects in the field, and prevention of captured insects from contacting the attractant compound (Pinto JRL, unpublished). In both seasons, traps were positioned at the center of each experimental plot. Sampling occurred every 3–4 days. During each sampling event, the attractant lure (25 mL for the ISCA Ball Trap and 300 mL for the Ajar® delta traps), the adhesive floor of the Ajar® delta trap, and/or the collection bag of the ISCA Ball Trap® containing any captured insects were replaced. Collected insects were brought to the laboratory for sorting, identification, and counting.

2.4.2 Larval sampling

To monitor infestations of *S. bosqueella* larvae, field surveys were conducted starting 15 days after plant emergence (DAE) and continued until 96 DAE (23 samples) and 86 DAE (24 samples) in the 2017/2018 and 2019/2020 seasons, respectively. Following the methodology of,[25] we recorded the number of larvae at each sampling point. At each plot, we scouted 10 sampling points every 3–4 days. At each sampling point, we examined three consecutive plants in a row and four randomly selected closed leaflets from each plant, resulting in a total of 120 leaflets examined per plot. Defoliation of the plants at the sampling point was estimated using a visual injury rating scale proposed by,[26] whose scale ranges from 1 (no injury) to 5 (76–100% of the leaflet consumed).

2.5 Determination of *Stegasta bosqueella* flight activity

Daily adult flight activity in the field was assessed by monitoring adult captures over a 24-h period (4 pm to 4 pm the next day) in the six experimental plots in the first season. Fresh attractant was placed in the traps before starting the monitoring period. Adult moth captures were counted every 2 h from 4 pm to 8 am, followed by a final count at 4 pm the next day.

2.6 Spatial and temporal distribution of *Stegasta bosqueella* larval feeding damage

The three 1-ha experimental plots in the first season that received the application of the attract-and-kill formulation described previously (Fig. 2A) were used for this study. Within each plot, a 10 m × 10 m grid was established, with 100 plants (sampling points) spaced equally apart. The sampled plants were flagged for easy identification (Fig. 2B). The GPS coordinates of each plant were collected using the C7 GPS Data application[27] to ensure consistent sampling of the same plants throughout the experiment. Feeding damage was assessed monthly at 30, 60, and 90 DAE, corresponding to the typical occurrence period of *S. bosqueella* larvae in peanut fields. Injuries were scored using the previously described visual injury scale.[26]

2.7 Data analysis

The effect of treatments, traps and sampling dates on the number of adults caught, as well as treatments and sampling dates on the number of *S. bosqueella* larvae and injuries, were analyzed using mixed models with repeated measures in time (PROC MIXED). All statistical procedures were performed using the SAS program.[28] To determine the spatial dependence of the injury caused by the larvae at different distances from the application swath, the semivariogram test was used, using the GS + program (2004). The SURFER 13.0 program[29] was used to prepare the spatial distribution maps of the injury assessed in the different months to verify the best application approach.

3 RESULTS

3.1 Effect of attract-and-kill on *Stegasta bosqueella* population

3.1.1 Adults season 2017/2018

The presence of *S. bosqueella* adults was confirmed in the area from the very first sampling, even before the emergence of peanut plants (Fig. 3A). Three applications of the attractive compound were performed at 30, 50, and 72 DAE and we observed that the applications resulted in a decrease in captured adults, especially when applied following a rise in trap captures. This is evident after the third application, performed at 72 DAE, which resulted in a significant decrease ($F_{1,106} = 4.32$, $P < 0.0001$) of captured moths in the attract-and-kill treated plots compared to the control. On average, at 73 DAE (following evaluation after spray), the number of captured *S. bosqueella* adults in plots with the attract-and-kill treatment was 2.4 folder lower (22.0 ± 2.5 in comparison of 52.0 ± 10.0) than the plots without the treatment. Despite the observed reduction in captures the number of *S. bosqueella* adults captured was not significantly influenced by the attract-and-kill treatment over time ($F_{1,106} = 1.00$, $P = 0.3195$). On the other hand, as expected, adult populations were significantly affected by the sampling dates ($F_{26,106} = 14.02$, $P < 0.0001$), indicating that *S. bosqueella* adult populations fluctuate over time.

Fewer adults were observed in the traps with the attract-and-kill treatment, with a 70% decrease at 53 DAE and a 62% decrease at 73 DAE. On average, this translates to a reduction from 27.0 ± 3.0 adults before application to 8.0 ± 2.0 adults after at 53 DAE and from 58.0 ± 16.4 adults before application to 22.0 ± 2.5 adults after at 73 DAE. No reductions were observed at 32 DAE due to the impact of rain one day after the application. Interestingly, the control treatment also exhibited a reduction in captured adults of 50% (average of 39.3 ± 9.5 adults before and 19.6 ± 1.8 after the application) and 17% (average of 63.0 ± 27.1 adults before and 52.0 ± 10.0 after the application) during this same period (53 and 73 DAE) (Fig. 3A).

3.1.2 Adults season 2019/2020

Similar to the observations in the first study (2017/2018), *S. bosqueella* adults were present in the area since the first sampling (Fig. 3A), again even before the emergence of peanut plants. The peak of adult populations for both treatment groups occurred at 69 DAE, with average captures of 97.2 ± 16.5 and 88.5 ± 16.2 adults per trap in the treatments with and without application of the attractive compound, respectively (Fig. 3A). Four applications of the attractive compound were performed at 31, 45, 55, and 69 DAE. These applications resulted in a reduction of captured *S. bosqueella* adults over time ($F_{1,141} = 5.33$, $P = 0.0224$). This effect was evident from the first application performed at 31 DAE ($F_{1,141} = 3.83$, $P = 0.0002$) and extended throughout most of the experiment (Fig. 3A). On average, 10.7 ± 2.4 and 19.5 ± 4.6 *S. bosqueella* adults were captured per trap in plots with the attract-and-kill treatment at 35 and 48 DAE (after spray application), respectively. In comparison, traps placed at plots without

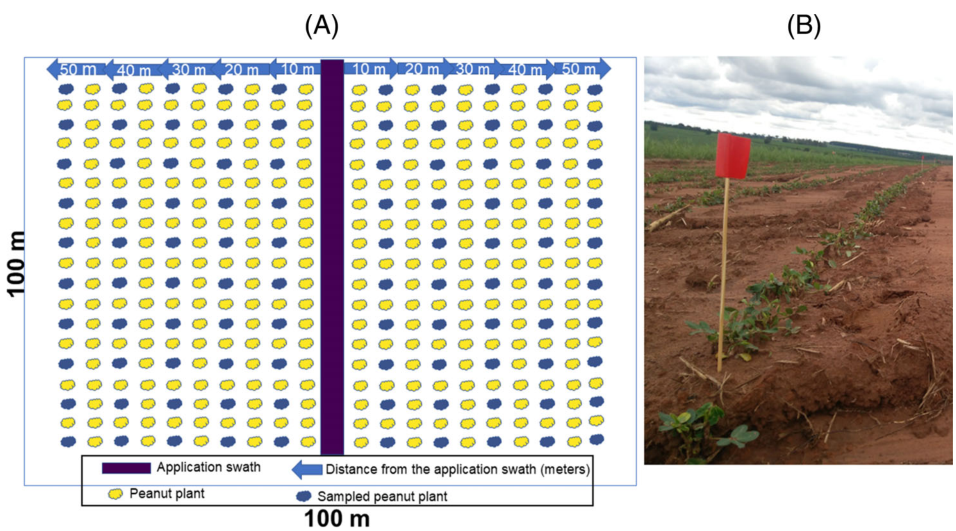

Figure 2. Description of the experimental plot design and data acquisition for spatial and temporal distribution analysis (A) and peanut plant flagged (B).

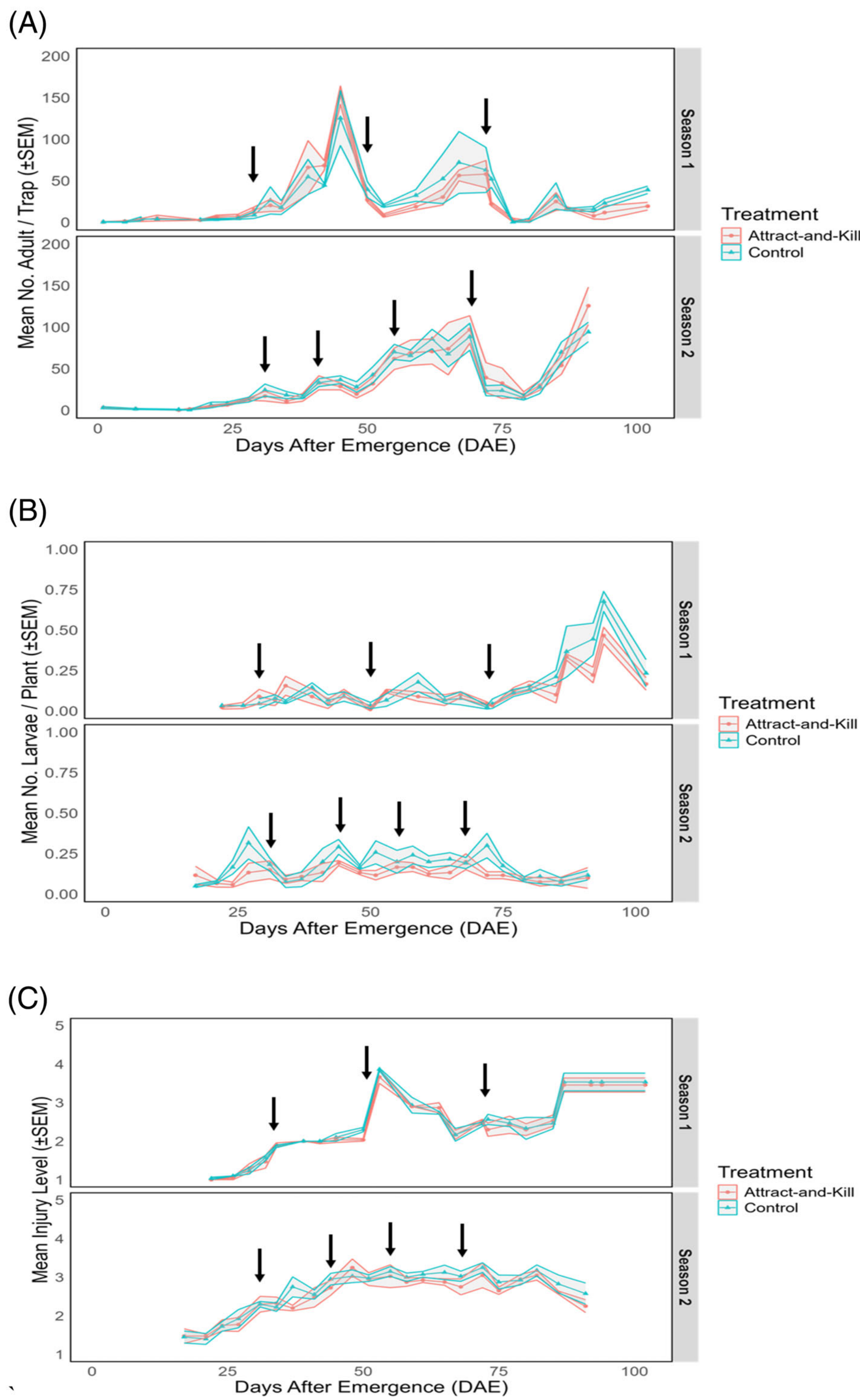

Figure 3. Average number of *Stegasta bosqueella* adults captured per trap (A), larvae per plant (B) and injury level (C) in the attractant-applied and control (without application) treatments from November 2017 to March 2018 (Season 1) and from November 2019 to February 2020 (Season 2). Average injury level ranges from 1 (no injury) to 5 (76–100% of the leaflet consumed). Shaded regions indicate treatment standard error and arrows represent treatment interventions.

the treatment captured 18.2 ± 4.23 and 28.0 ± 6.2 adults per trap at the at 35 and 48 DAE, indicating about two times more adults captured in traps located in untreated plots compared to those that received the treatment.

Fewer adults were captured in the traps with the attract-and-kill treatment, with a 37% decrease at 35 DAE, 32% at 48 DAE, and 60% at 72 DAE (Fig. 3-A). On average, this implies a reduction from 17.0 ± 5.8, 28.7 ± 4.1 and 97.2 ± 16.5 adults before application to

10.7 ± 2.4, 19.5 ± 4.8 and 39.2 ± 18.1 adults after application, respectively (Fig. 3A). However, rain hampered the effectiveness of the third application at 55 DAE (no reduction observed). Similarly to the first season, the control treatment also exhibited a reduction in captured adults of 25%, 24% and 73% (reduction from 24.2 ± 7.3, 36.7 ± 4.7 and 88.5 ± 16.5 adults before application to 18.2 ± 4.2, 28.0 ± 0.6.2 and 23.5 ± 6.1 adults after application) during this same period (35, 48, and 72 DAE) (Fig. 3A).

Stegasta bosqueella adult populations were significantly influenced by sampling dates ($F_{1,141} = 33.22$, $P < 0.0001$), indicating that populations fluctuate over time. Importantly, there was no interaction between the application of the attractive compound and the sampling dates ($F_{24,141} = 0.55$, $P = 0.9563$). This suggests that both factors, treatment application and sampling dates, affect *S. bosqueella* adults independently.

3.1.3 Larvae and injury season 2017/2018

Contrary to expectations, there was no significant difference in the average number of larvae recorded ($F_{1,90} = 3.16$, $P = 0.0790$) or the average defoliation ($F_{1,90} = 1.52$, $P = 0.2215$) over time between the treatments. Although not statistically significant, during the larval population peak observed in all plots at 94 DAE (Fig. 3B), the control plot had a slightly higher number of larvae (0.67 ± 0.06 larvae/plant) compared to the attract-and-kill treatment (0.47 ± 0.05 larvae/plant), on average (Fig. 3B). Throughout most of the study period, regardless of treatment, the defoliation caused by *S. bosqueella* larvae on the plants ranged from rate 2 (1–25% leaf area consumed) to rate 3 (26–50% leaf area consumed) (Fig. 3C).

3.1.4 Larvae and injury season 2019/2020

Applications of the attractive compound resulted in a reduction of *S. bosqueella* larvae ($F_{1,128} = 13.78$, $P = 0.0003$), as observed through sampling every 3–4 days. Throughout the study, *S. bosqueella* larval densities remained below 0.4 larvae per plant in both treatment areas (Fig. 3B). The highest larval densities (0.32 ± 0.10 and 0.30 ± 0.07 larvae per plant) were observed in the control treatment at 28 and 72 DAE, respectively (Fig. 3B). This implied a roughly threefold reduction in larvae per plant in the attract-and-kill treatment (0.13 ± 0.05 and 0.11 ± 0.02 larvae per plant) compared to the control (2.6 and 2.4 times higher).

The control treatment exhibited significantly greater defoliation caused by *S. bosqueella* larvae ($F_{1,128} = 7.39$, $P = 0.0075$) (Fig. 3C). However, it remained between rate 2 (1–25% leaf area consumed) and 3 (26–50% leaf area). The highest injury averages were observed in the treatment without application at 55 (3.15 ± 0.13) and 72 (3.25 ± 0.12) DAE, also corresponding to the period of the highest occurrence of larvae.

3.2 *Stegasta bosqueella* flight activity

The peak flight activity of *S. bosqueella* adults occurred between 6 pm and 9 pm, with 90% of moths captured during this period. This was determined by monitoring trap captures in each experimental plot. Minimal captures (10%) were observed between 10 pm and 5 am, and no captures were recorded between 5 am and 4 pm.

3.3 Spatial and temporal distribution of *Stegasta bosqueella* injury

A strong positive spatial dependence in *S. bosqueella* larval injury was observed between 20 and 25 m (Table 1). This trend was observed throughout the monthly collections, with lower injury scores (grade 1, indicating no defoliation) concentrated near the application zones (Fig. 4). Conversely, higher injury scores (rates 2 and 3) indicating greater defoliation (25–50% leaf area consumed) were observed for *S. bosqueella* larvae beyond 25 m from the treatment application swath. The spatial dependence models in Table 1 indicate a strong effect within a 20–25-m range. This is supported by the low error (MSE) and high accuracy (R^2) values, suggesting robust estimations. Therefore, based on this study, a new configuration for treatment application was established for the 2019/2020 season, using two strips spaced 50 m apart. The total volume used remained the same as in the first season by adopting intermittent spraying, with the nozzles being turned on and off every 1.5 m.

4 DISCUSSION

We confirmed, through field trials conducted in two growing seasons and different locations, that the attract-and-kill strategy can be a viable tool to reduce the Rednecked Peanutworm populations in peanut crops, a major pest of peanut crops in the Americas. The findings provide valuable insights into the feasibility and effectiveness of this strategy in practical agricultural settings. The application of attract-and-kill strategies for pest management has garnered significant interest due to its effectiveness in reducing insect pest populations as well as being an environmentally friendly alternative to traditional chemical insecticides. For decades, peanut lepidopteran control in various locations has

Table 1. Variogram parameters and interpolation coefficients adjusted for plant distribution maps with symptoms of injury caused by *Stegasta bosqueella* larvae in the 2017/2018 season

Area	Month	Model	C0	C0 + C1	MSE[a]	Range (m)	R^2
1	1	Spherical	0.1293	0.3716	0.0275	26.9000	0.681
	2	Spherical	0.1985	0.3980	0.0106	22.2000	0.715
	3	Spherical	0.2250	0.7100	0.0226	21.7000	0.891
2	1	Spherical	0.2515	0.4070	0.0055	15.0000	0.456
	2	Spherical	0.1900	0.4447	0.0116	25.0000	0.622
	3	Spherical	0.2842	0.8250	0.0538	22.0000	0.744
3	1	Spherical	0.2154	0.4346	0.0148	30.0000	0.605
	2	Spherical	0.0060	0.5660	0.0179	36.0000	0.501
	3	Spherical	0.4019	0.7995	0.0552	30.0000	0.620

[a] Mean square error.

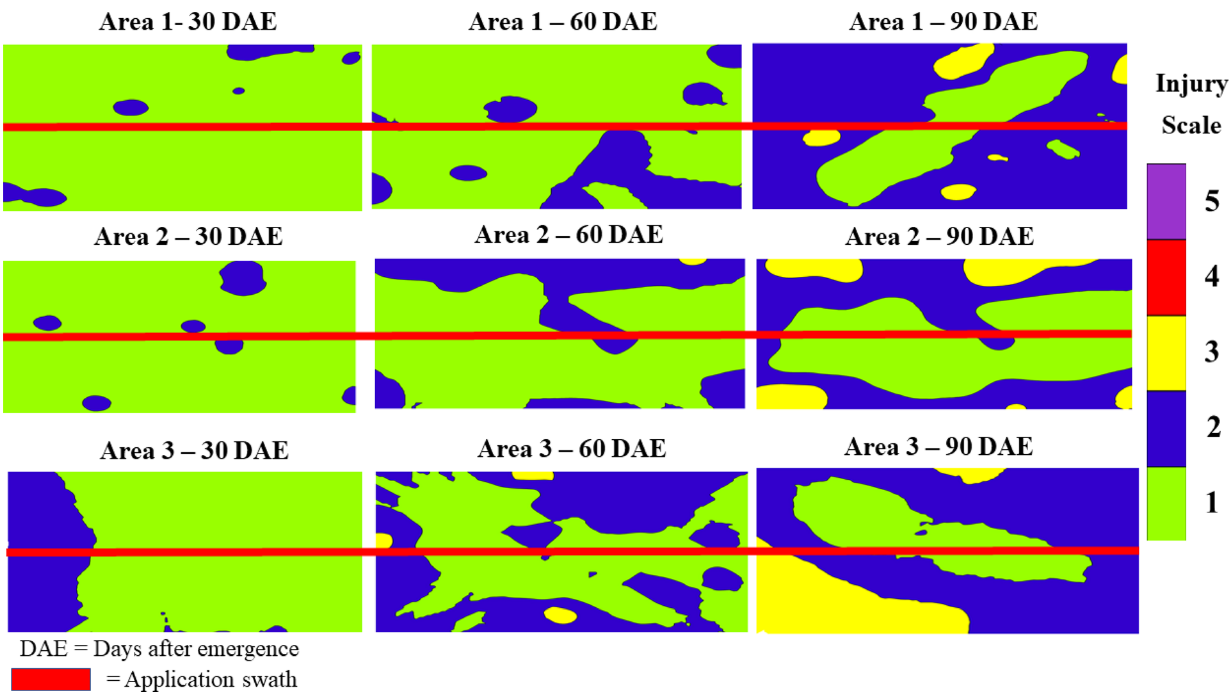

Figure 4. Variability maps of plants defoliated by *S. bosqueella*, in three evaluations periods, in areas 1, 2 and 3. The color scale means injury severity.

relied solely on applying insecticides targeting exclusively the larval stage.[10,13,30]

Field trials showed that several factors are key to the success of the attract-and-kill strategy in reducing *S. bosqueella* adults, and subsequent larvae and crop damage in peanut. These factors include prompt intervention upon detection of increased adult trap catches and understanding the peak of adult movement in the field in order to align application timing with the main period of adult activity (in our case between 6 pm-9 pm). Our findings align with previous research demonstrating the efficacy of attract-and-kill strategies in managing various agricultural pests but emphasize the need to consider factors such as environmental conditions and specific pest behavior.[31–34] For instance, in our study, rain shortly after application (at 32 DAE in the first season and 55 DAE in the second season) significantly reduced the effectiveness of the attract-and-kill treatment. This fact highlights the importance of growers to consider these factors in order to optimize application timing and avoid situations where efficacy is compromised by unfavorable weather and insect life stage conditions and suggests that the formulations resistant to runoff ought to be developed. Also, to further enhance the use of this technology in other locations, additional studies are required to address the effect of environmental factors on the attract-and-kill formulation, such as solar radiation. According to previous research, solar radiation can affect the attractant durability and performance in the field.[33]

Strategic treatment placement, based on pest behavior, emerged as another key factor. The application of the attractant compound associated with insecticide in the first season failed to reduce adult populations or lessen larvae abundance and leaf damage. This lack of effect might be due to insufficient application, *i.e.*, one strip per plot might not have been enough to attract and control adults across the field. Since this was the first application of the attract-and-kill strategy for *S. bosqueella* in peanuts, knowledge about optimal timing for adult control was limited. As understanding insect behavior in agroecosystems is crucial for effective pest management,[35] the information obtained during the first season on spatial and temporal distribution defined a new application strategy, which was implemented in the second season. This resulted in a significant reduction of the *S. bosqueella* population and consequently decreased damage to peanut plants. Therefore, we observed that to optimize attract-and-kill efficiency for *S. bosqueella* management in peanuts, applications should be performed on strips spaced up to 50 m apart. This ensures attraction and mortality of *S. bosqueella* adults within a 1-ha radius. Moreover, to achieve the same total volume of attractant used in the first season, we used two strips with intermittent spraying (turning the nozzles on and off at every 1.5 m).

The reduction in captured adults observed on both seasons in the untreated plots, likely due to insects moving from surrounding peanut fields, suggests that the food attractant itself might have had a widespread effect on adult populations, possibly causing them to disperse from the trapping in the control areas. This is supported by studies using the attract-and-kill strategy conducted on cotton.[35,36] These studies found no reduction in adult infestation in fields adjacent to treated areas, but a decrease in distant areas without application. This emphasizes that although the population reduction in peanut crops can be greater in the areas with application, the impact can also occur in the adjacent areas.

The early detection of *S. bosqueella* adult even before peanut emergence is likely due to the presence of volunteer peanut plants. This occurs because peanuts in São Paulo state, Brazil region are often rotated with sugarcane. These renewed areas, containing volunteer plants, are frequently located near peanut fields and act as refuges for insects, attracting pests and diseases to the main crop. Therefore, implementing the attract-and-kill strategy in peanuts, particularly as an initial management practice in areas with volunteer peanut plants, could be advantageous. It can help reduce early problems with defoliators right after peanut emergence. Furthermore, since peanuts host a wide variety of moths 361 011, the attract-and-kill strategy has the potential to target adults from surrounding vegetation, before establishment of peanut plants in the field.

The next research step is to conduct an economic feasibility analysis comparing the management costs of attract-and-kill *versus* conventional pest management practices. Low adoption of IPM is generally linked to high scouting costs and a lack of awareness regarding the cost–benefit ratio.[37–39] This is because IPM interventions are based on actual pest populations rather than a calendar-based schedule. Additionally, when assessing the possible role of attract-and-kill formulations in integrated pest management, it is crucial to take into account their impact on non-target organisms. In certain instances, the use of semiochemicals in attract-and-kill formulations can impact non-target organisms.[40,41] Consequently, it is crucial to thoroughly investigate the impact of attract-and-kill strategies on non-target species to mitigate any adverse effects and ensure compatibility within a IPM program.

Sustainable production systems that prioritize high-quality food and minimal use of persistent chemicals are in high demand among consumers worldwide. Unlike conventional broad-spectrum insecticides, the attract-and-kill strategy aligns with IPM principles and can enhance the effectiveness of IPM programs in peanut, considering economic, ecological, and social factors.

5 CONCLUSIONS

Field trials conducted in commercial peanut fields over two growing seasons demonstrate the potential of the attract-and-kill strategy as an effective and environmentally friendly method for managing the Rednecked Peanutworm. Key findings from our study include: (1) prompt intervention upon detection of increased adult trap catches is crucial. Knowing the peak adult activity in the field allows for product application when adults are most active, which is important for maximizing efficacy; (2) rainfall can significantly affect treatment efficacy, highlighting the importance of developing formulations resistant to runoff to ensure the technique's effectiveness under various weather conditions; and (3) strategic treatment placement based on pest behavior, using spatial and temporal distribution data, we observed that to optimize attract-and-kill effectiveness against *S. bosqueella* in peanuts, trap placement should be spaced 50 m apart.

The reduction in pest populations and achieved pest control through the attract-and-kill strategy suggests that it can be a valuable addition to peanut IPM programs. We propose that implementing the attract-and-kill strategy in peanuts as an initial suppression tactic could effectively reduce early defoliator problems from the time of plant emergence. Additionally, since peanuts can host a wide variety of moths, this approach can potentially control not only *S. bosqueella*, but adult moths from other species.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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