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IMPACT OF SPRAYS ON BAITS IN CONTROLLING GERMAN COCKROACHES, *BLATTELLA GERMANICA*

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Abstract Combinations of bait and spray were tested against susceptible and field-collected German cockroaches, *Blattella germanica*. In exposure tests, residual deposits of all sprays were lethal to a susceptible strain, but pyrethrin and certain pyrethroid sprays were repellent in choice boxes. Indoxacarb bait provided nearly 100% kill of all strains tested, whereas there was a slight decline in activity with clothianidin bait. Indoxacarb bait was effective when applied on treated surfaces or after being sprayed and negated repellency and resistance. The activity of clothianidin bait declined when combined with repellent pyrethrin and certain pyrethroid sprays. In summary, for the best control, apply baits to untreated areas and avoid spraying them.

Key words *Blattella germanica*, resistance, repellency, Ebeling choice box

INTRODUCTION

For the past 25 years, gel baits have been one of the standard tools to control *B. germanica* (Appel and Rust, 2021). Baits are frequently utilized along with sprays to control German cockroaches by pest management professionals, especially in commercial accounts. Conventional wisdom states that baits should not be placed where they may be contaminated with insecticidal spray. Still, there has been very little research regarding the interaction of baits and sprays. Baits contaminated by mint oil sprays and silica aerogel dust had reduced consumption and increased the time required to kill *B. germanica* (Appel 2004).

A survey of four large pest management firms in California provides us with a list of sprays and baits used in their commercial accounts. Those sprays and baits were tested against laboratory and field-collected strains of *B. germanica*.

METHODS AND MATERIALS

Insects A susceptible strain of *B. germanica* (UCR) has been maintained in the laboratory for 43 years without any exposure to insecticides. Strain WM was collected in public housing in Los Angeles, California, in 2018. D and E were insecticide-resistant strains obtained from Auburn University. The cockroaches were maintained at 26.7 ± 2 °C and relative humidity of 30–50% in 127-liter garbage cans with electric barriers along the upper inner rim to prevent them from escaping. Dry dog chow and water were provided *ad libitum*. The cockroaches were lightly gassed with CO_2 (< 2 min), and adult males were selected for the study. They were allowed 5–6 h to recover before testing.

Insecticides The **sprays** were 0.025% β-cyfluthrin (Tempo® SC Ultra, Bayer Environmental Science, Research Triangle Park, NC), 1% pyrethrin + 5% piperonyl butoxide [PBO] (ULD BP-100, BASF Corp., Research Triangle Park, NC), and 6% pyrethrin + 60% PBO (ExciteR™, Central Garden & Pet Company, Schaumburg, Il), 0.25% permethrin (Tengard®, United Phosphorus Inc., King of Prussia, PA), and 0.03% deltamethrin (Suspend® Polyzone, Bayer Environmental Sci.). The tested **baits** were 1% clothianidin bait (MaxForce® Impact™ Roach Gel Bait, Bayer Environmental Sci.) and 0.6% indoxacarb bait (Advion® Evolution, Syngenta Crop Protection, Greensboro, NC).

Treatment of Panels and Baits The various sprays were applied to rectangular panels (30.8 by 15.2 by 0.8 cm) and squares (11 by 11 by 0.8 cm) of unpainted plywood with an airbrush. The 1% pyrethrin was applied at a rate of 4.1 mg/m^2. The panels were sprayed with 3 ml of 0.25% permethrin (160 mg/m^2), 0.03% deltamethrin (9 mg/m^2),

0.025% β-cyfluthrin (7.5 mg/m^2), and 6% pyrethrin (154 mg/m^2). The treated panels were allowed to dry for 24 h before being tested. A dollop of bait (≈ 0.5g) was placed in the center of a plastic weighing boat. The baits were sprayed at the same rates described above and allowed to dry for 24 h. The sprayed and unsprayed baits were placed in clean weighing boats.

For each cockroach strain, the following choice box experiments were conducted with each spray and bait: (1) untreated panel, (2) unsprayed bait, (3) sprayed bait, (4) sprayed panel, (5) sprayed panel and unsprayed bait, and (6) sprayed panel and sprayed bait.

Continuous Exposure Studies To determine the residual insecticidal activity of the sprays, ten adult males UCR strain were continuously confined to squares of unpainted plywood treated with the sprays. The inside surface of glass rings (ID 6.5 cm by 4 cm) and a large glass petri dish lid (ID 9.7 cm by 18 mm) were coated with Teflon to confine the cockroaches to the treated surface. The rings were affixed to the treated squares with hot glue. Five replicates were tested for each spray and an untreated surface. The number of dead insects was counted regularly every 30 min for the first 4.5 h and then every several hours for the next 30 h.

Choice Box Tests The 1-day-old residual deposits of the sprays, baits, and combinations were tested in Ebeling choice boxes (Rust et al., 1993). The treated panels were inserted into the dark compartment, and untreated or treated baits were placed in the center of the dark compartment or on the sprayed panels. Twenty adult male cockroaches were confined in the light compartment for 5–6 h before being allowed access to the dark compartment. The choice boxes were placed in a room on a photoperiod of 12:12 h (L:D). The number of dead and live cockroaches in the light and dark compartment was counted daily for up to 14 d. Three replicates were conducted for each spray, bait combination, and cockroach strain.

The performance index (PI) combines the effects of mortality and repellency in the choice box and estimates potential field performance. The PI is calculated as follows:

$$PI = 1 - \left(\frac{\text{Number alive + Number alive in light side}}{\text{Number dead + Initial total number}} \right) \times 100$$

Complete repellency and no mortality results in a PI = -100. Complete mortality and no repellency results in a PI = +100. In the control boxes, no mortality and no repellency results in a PI = 0 (Rust and Reierson 1978, Wu and Appel 2018).

Data Analysis The continuous exposure data were analyzed with Kaplan-Meier tests (Statistix 10, 2018). The survival distributions [S(t)] and the survivorship percentiles were calculated for each treatment.

RESULTS AND DISCUSSION

Continuous Exposure Studies Deposits of β-cyfluthrin provided the fastest kill of *B. germanica* (UCR strain) with a survival probability of 0.4 at 0.5 h (Table 1). The survival probability of males exposed to 1-day-old deposits at 1 h was pyrethrins > deltamethrin > β-cyfluthrin = permethrin. Permethrin, β-cyfluthrin, and deltamethrin killed all insects in 2 h.

All treated panels killed adult males. Repellency is inversely related to the speed at which the toxicant knocks down cockroaches (Rust and Reierson, 1978). β-cyfluthrin had the lowest survival probability at 0.5 h of all the sprays tested, but the treated panels provided a PI = 100 within 7 days in choice boxes. The suspended concentrate formulation contributed to its increased bioavailability and toxicity. A similar explanation also accounts for the high PI values in choice boxes with deltamethrin deposits.

Choice Box Tests Sprayed Panels When tested against the UCR strain, the β-cyfluthrin and deltamethrin sprays resulted in PIs = 100 and 95.7 at day 14, respectively. The permethrin spray provided some mortality (PI = 54.9). The two pyrethrin sprays were repellent, and the males remained on the untreated vertical panels in the dark compartment. When tested against strain WM, none of the sprays killed cockroaches, with more surviving males in the light compartment than the UCR strain. The results were similar to the field-collected strains D and E.

Table 1. The survival probability S(t) of UCR males confined on 1-day-old deposits.

	Hour 0.5			Hour 1.0			Hour 4.5		
Toxicant	**95% C.I.**	**S(t)**	**95% C.I.**	**95% C.I.**	**S(t)**	**95% C.I.**	**95% C.I.**	**S(t)**	**95% C.I.**
β-cyfluthrin	**0.32**	**0.4**	**0.55**	**0.08**	**0.1**	**0.22**			
deltamethrin	**0.58**	**0.7**	**0.84**	**0.23**	**0.3**	**0.45**			
6% pyrethrin	**0.68**	**0.8**	**0.92**	**0.63**	**0.8**	**0.90**	**0.43**	**0.6**	**0.75**
1% pyrethrin	**0.52**	**0.7**	**0.79**	**0.35**	**0.5**	**0.65**	**0.14**	**0.2**	**0.37**
permethrin	**0.55**	**0.7**	**0.87**	**0.04**	**0.1**	**0.10**			
Untreated		**-**			**-**			**-**	

Unsprayed Bait Indoxacarb bait provided PI values > 95 at day 14 for all strains. Clothianidin bait killed 100% of the UCR strain by day 7 but provided lower PI values against the three field strains (WM = 81.2, D = 94.4, E = 88.5).

Sprayed Bait When indoxacarb and clothianidin baits were sprayed with the five insecticides and tested against the UCR strain, the PI values for the sprayed and unsprayed baits were similar. The sprayed and unsprayed baits provided 100% kill of the cockroaches, typically within a few days. There was no noticeable impact of applying sprays to baits. When indoxacarb bait was sprayed with pyrethrin and pyrethroids, the PI values for the WM strain were > 97 at day 14. Similar results occurred with strains D, and E. Sprayed baits were as effective as unsprayed baits against these strains.

Certain sprays adversely affected the performance of clothianidin bait. When clothianidin bait was sprayed and tested against WM, the 6% pyrethrin and permethrin sprays decreased the PI values by 52.7 and 28.5 points, respectively, compared with clothianidin bait alone (PI = 81.2). The PIs for β-cyfluthrin and deltamethrin sprayed bait were 86.1 and 93.8 on day 14, respectively.

Sprayed Panels and Unsprayed Bait When tested against the UCR strain, clean dabs of clothianidin bait on the 1% and 6% pyrethrin, β-cyfluthrin, and deltamethrin sprayed panels provided PIs of 100 by day 14. The PI value at day 14 for permethrin sprayed panels and clothianidin bait was 96.7. The indoxacarb baits overcame the repellency, especially for the pyrethrin and permethrin sprays. Cleans dabs of indoxacarb bait on 1% pyrethrin and β-cyfluthrin panels resulted in PIs = 100 by day 7 when tested on UCR. The PIs for 6% pyrethrin, deltamethrin, and permethrin at day 14 were 92.1, 98.3, and 89.2. Clean dabs of clothianidin bait on the 6% pyrethrin, β-cyfluthrin, deltamethrin, and permethrin sprayed panels at day 14 provided PIs of 76.2, 74.3, 93.0, and 57.9, respectively, on WM strain. Only the combination of deltamethrin and clothianidin effectively overrides the repellency and resistance. Clean dabs of indoxacarb bait on the 6% pyrethrin, β-cyfluthrin, deltamethrin, and permethrin sprayed panels at day 14 provided PIs of 97.4, 96.5, 98.3, and 93.3 on WM strain. Indoxacarb bait was effective in overriding the repellency and resistance.

Sprayed Panels and Sprayed Bait When tested against the UCR strain, sprayed dabs of clothianidin bait on 1% pyrethrin, 6% pyrethrin, β-cyfluthrin, and deltamethrin sprayed panels provided PIs of 100 by day 14. The PI of the combination of permethrin sprayed bait, and permethrin sprayed panel was 83.5. Sprayed dabs of indoxacarb bait on 1% pyrethrin, β-cyfluthrin, and deltamethrin provided PIs of 100 by day 14. The PIs declined to 25.6 and 71.6 for 6% pyrethrin and permethrin and sprayed bait.

When tested against the WM strain, there was a decline in the PIs on the sprayed dabs of clothianidin bait on 6% pyrethrin, β-cyfluthrin, and permethrin sprayed panels. Only the combination of deltamethrin sprayed panels and clothianidin baits resulted in provided PIs > than 90 at day 14. The combinations of sprayed panels and baits for 1% and 6% pyrethrin, β-cyfluthrin, deltamethrin, and permethrin resulted in PIs > 98 at day 14. The indoxacarb bait sprayed on sprayed panels overrode the resistance and repellency, providing 100 % kill with all sprays except 6% pyrethrin (98.5).

The Ebeling choice box was designed to examine the repellency of insecticidal dusts and sprays and the avoidance behavior of cockroaches (Ebeling et al., 1996). In addition, they have been used to determine the effectiveness of commercial baits to control *B. germanica* (Appel 1990). Their utility has been expanded to include field-collected strains of *B. germanica* and examine the interaction of insecticide resistance and repellency on control (Rust and Reierson, 1991; Wu and Appel, 2018).

The strains D, E, and WM are resistant to pyrethroids (Wu and Appel, 2018). Lee et al. (2022) reported that the LD_{95} of deltamethrin for the UCR strain was 11.3 ng/male and that < 10% of the males of WM were killed when exposed to a diagnostic dose (3 x LD_{95} UCR strain). In addition, strain WM showed decreased susceptibility to clothianidin and indoxacarb (Lee et al., 2022). Panels treated with β-cyfluthrin and deltamethrin killed susceptible strains but were totally ineffective against D, E, and WM. Baits were generally effective, but clothianidin bait was least effective against WM (PI = 81.2).

CONCLUSIONS

Repellent sprays altered the activity of the clothianidin bait and should be avoided, whereas this effect was not observed with indoxacarb bait. The reasons for this difference are unknown, and additional research is warranted.

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