

# PERFORMANCE OF COCKROACH GEL BAITS AGAINST SUSCEPTIBLE AND BAIT AVERSE STRAINS OF GERMAN COCKROACH, *BLATTELLA GERMANICA* (DICTYOPTERA : BLATTELLIDAE) - ROLE OF BAIT BASE AND ACTIVE INGREDIENT

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**Abstract** Three experimental gel matrices containing indoxacarb and three market-leading Maxforce gels containing either fipronil or hydramethylnon were evaluated and the roles of active ingredients and bait bases in the bait performance were examined against both lab susceptible and bait averse strains of German cockroach, *Blattella germanica*. For lab susceptible Orlando cockroaches, most cockroach gel baits performed very well regardless of the type of active ingredients or bait bases. For bait averse Miami cockroaches, bait matrices turned out to be the determining factor for control. For currently available products, both the Maxforce FC gel containing fipronil and Maxforce gel containing hydramethylnon were not efficacious, but Maxforce FC Select gel with fipronil showed excellent efficacy against Miami cockroaches. For the experimental gels, even the newly-developed bait base, which had never been introduced into the field, was subject to bait aversion problems. Still, indoxacarb gel baits using the best of three matrices (Advion-C) showed excellent efficacy against both susceptible and bait averse cockroaches.

**Key Words** Inert ingredient, bait aversion, indoxacarb

## INTRODUCTION

Cockroach baits, especially in the gel form, have been used extensively for control of the German cockroach, *Blattella germanica* (L.), by pest management professionals (Reierson, 1995). An insecticidal bait consists of an active ingredient and inert ingredients (bait base) that make up the major portion of the bait. Many insecticides have been shown to have excellent potential as bait active ingredients including abamectin (Koehler et al., 1991; Rose, 1993), hydramethylnon (Appel, 1990), fipronil (Kaakeh et al., 1997), imidacloprid (Appel and Tanley, 2000), and boric acid (Gore and Schal, 2004). In comparison, research on the roles of inert ingredients or bait bases in bait performance has been lacking and mostly associated with studies on bait aversion. It has been documented that cockroaches can develop bait aversion to inert ingredients in the bait base after extensive use of baits and the bait base must be modified to maintain its effectiveness (Silverman and Bieman, 1993). Recently, control failure with Maxforce gels, the most heavily used baits, was found against some populations of the German cockroaches and it was reported that the cause was bait avoidance and not physiological insecticide resistance (Wang et al., 2004). However, increased levels of physiological tolerance have also been found in many German cockroach populations even those with no prior exposure to fipronil (Valles et al., 1997; Holbrook et al., 2003). Bait manufacturers can counter the control failure problem by introducing new baits containing either different bait bases or different active ingredients. Recently, Bayer Crop Science introduced Maxforce FC Select roach gel that contains the same 0.01% fipronil but with a different bait base (Morrison et al., 2004).

In this study, we conducted an evaluation of three new gel bait bases containing a new insecticide, indoxacarb (McCann et al., 2001), for control of cockroaches. We examined the importance of bait base on the bait efficacy against susceptible and bait averse cockroaches. Similar examination was made with baits containing fipronil, which is incorporated into two different bait bases in the original Maxforce FC gel and recently introduced Maxforce FC Select gel, respectively. We found that all gel baits containing indoxacarb and fipronil performed well against susceptible cockroaches regardless of their bait bases. However, only gels with special bait bases were effective against bait averse cockroaches. In addition, it was discovered that bait bases might have aversion problems even when they have never been used in the field.

## MATERIALS AND METHODS

**Insects.** Two strains of German cockroach, *Blattella germanica*, were used. The Orlando normal strain is the susceptible cockroach strain and has been reared in laboratories for an extended period (Silverman and Liang, 2001). The Miami strain was collected in 1999 from a location in Miami, FL, where application of Maxforce FC gel failed to control the cockroach populations. Selection pressure was applied to the Miami strain colony during lab rearing by applying FC gel to the colony approximately once every three months. Both strains were reared in a room with temperature at  $27 \pm 1.0^\circ\text{C}$ , about 50% relative humidity, and 12:12 light/dark cycle. Purina dog chow and water were provided *ad libitum*.

**Baits.** Three commercial gel baits were used including Maxforce FC gel containing 0.01% fipronil, Maxforce gel containing 2.15% hydramethylnon, and Maxforce FC Select gel containing 0.01% fipronil, all manufactured by Bayer Environmental Science, Research Triangle Park, NC. Advion gel baits containing experimental bait bases A (Advion-A) and B (Advion-B) were supplied by DuPont Crop Protection, Wilmington, DE. Advion gel containing experimental bait base C (Advion-C) was made in the lab using technical indoxacarb. Indoxacarb were incorporated into each experimental bait base at 0.1%, 0.5%, and 1.0% levels.

**Efficacy Trial.** Efficacy trials were conducted in conditions that were the same as rearing. Standard lab arenas (40 x 27 x 21 cm) were used. A petroleum jelly and mineral oil mixture was applied to the arena inner wall top half to prevent cockroaches from escaping. About 50 cockroaches (15 males, 10 non-gravid females, and 25 mid-size nymphs) were used in each arena. Insects in the different arenas were similar in sizes, developmental stages, and were collected from the same source. Cockroaches were acclimated in the arenas for three (3) days with dog chow and water *ad libitum* on one side of the arena. Harborages made of compressed cardboard boxes were provided at the opposite end of the arena.

After the acclimation period, all arenas were checked and all dead cockroaches, if any, were removed and replaced. About one gram of bait was placed into a small Petri dish (4 x 0.5 cm) and introduced at the arena side opposite the harborage. In the control, only Purina dog chow was available. Mortality of cockroaches was checked daily for 7 days. Cockroaches were considered dead if they could not run away when flipped over with a pair of forceps.

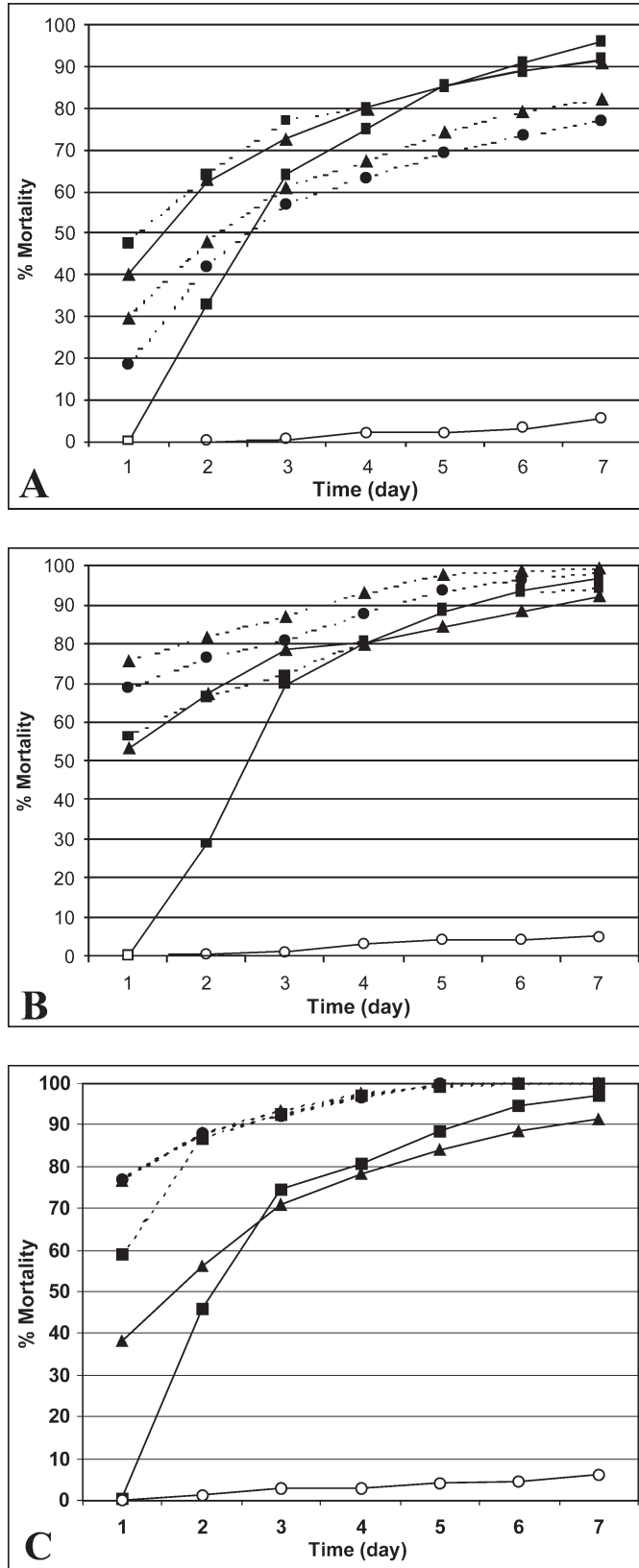
**Data Analysis.** Four (4) replicates were conducted for each bait treatment and control. Control treatments were conducted for each cockroach strain in each efficacy trial conducted separately. Final treatment mortalities were corrected by control mortality using the Abbott formula (Abbott, 1925) and analyzed with ANOVA using General Linear Model. The  $LT_{50}$  and  $LT_{95}$  values were obtained by Probit analysis assuming Weibul distribution of data (Minitab Inc., 1998) and two values were considered different if their 95% confidential intervals were not overlapped.

## RESULTS

Under our study protocol, both Maxforce FC and hydramethylnon gels performed consistently well against the lab susceptible Orlando normal strain cockroaches in all 3 efficacy trials (Figure 1). The FC gel killed more quickly resulting in a shorter  $LT_{50}$  but hydramethylnon gel always had a shorter  $LT_{95}$  (Table 1).

Using Maxforce FC and hydramethylnon gels as standard, we found that the efficacy of the Advion gels improved progressively when bait base changed from A to B, and from B to C (Figure 1). All of the mortality curves for Advion gels ran parallel to that of FC gel suggesting that the speed of kill of indoxacarb was similar to fipronil but faster than hydramethylnon. Performances of Advion-A gels were similar or worse, while that of Advion-B gels became similar or better than the FC gel (Table 1). One reason for the improvement to Advion-B gels was a reduction in the amount of an adjuvant associated with indoxacarb. The lower performance of Advion-A gels containing higher indoxacarb was also due to the higher percentage of the adjuvant.

All Advion-C gels were significantly more efficacious than the FC gel (Table 1). With the exception of the first day when the Advion-C gel with 0.1% indoxacarb had lower mortality than those containing 0.5% and 1.0% indoxacarb, mortalities at all other days were nearly identical among the 3 Advion-C gels containing 0.1%, 0.5%, and 1.0% indoxacarb, respectively (Figure 1C). Of all the gels tested, Advion-C gels were the only baits achieving 100% mortality before day 7. All Advion-C gels had significantly shorter  $LT_{50}$ s and  $LT_{95}$ s, and higher final mortalities than both the Maxforce FC and hydramethylnon gels (Table 1).

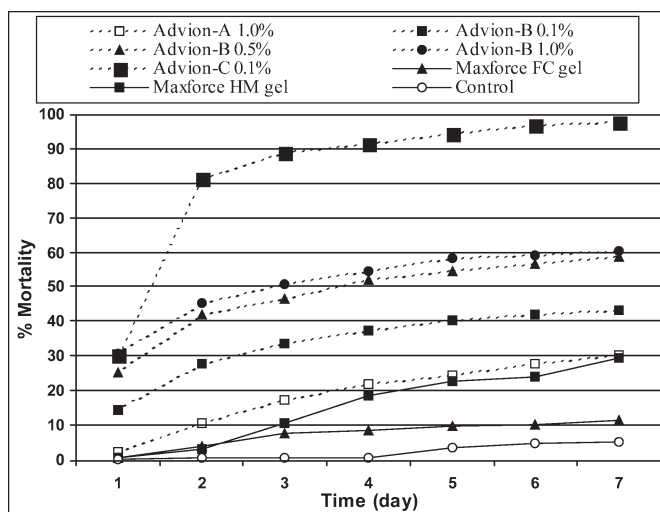


**Figure 1.** Mean mortality of susceptible Orlando strain cockroaches under bait treatments. Solid lines are for commercially available Maxforce FC gel containing 0.01% fipronil (triangle symbols) and Maxforce gel containing 2.15% hydramethylnon (square symbols). Dashed lines are for experimental Advion gels containing indoxacarb at 0.1% (square symbols), 0.5% (triangle symbols), and 1.0% (circle symbols) levels. Control treatment is represented by solid line with open circles. Results on Advion-A, -B, and -C are presented in A, B, C, respectively.

**Table 1.** Summary statistics for efficacy trials against lab susceptible Orlando normal cockroaches. All Advion gels contain indoxacarb at the levels indicated. Maxforce FC gel contains 0.01% fipronil and Maxforce HM gel is the Maxforce gel containing 2.15% hydramethylnon. Three separate trials were conducted at different time. Values followed by the same letter within each trial were not significantly different from each other ( $P < 0.05$ ).

	<b>Bait Treatment</b>	<b>LT<sub>50</sub> (95% CI) (day)</b>	<b>LT<sub>95</sub> (95% CI) (day)</b>	<b>% Final mortality (Mean ± SEM)</b>
Orlando Strain Trial #1	Advion-A 0.1%	1.10 (0.85-1.33) a	9.35 (7.91-11.67) bc	91.2 ± 2.7 a
	Advion-A 0.5%	2.18 (1.89-2.44) b	13.44 (11.14-17.25) c	81.1 ± 2.5 ab
	Advion-A 1.0%	2.81 (2.53-3.09) c	13.93 (11.64-17.65) c	75.8 ± 12.6 b
	Maxforce FC gel	1.37 (1.12-1.60) a	8.91 (7.71-10.74) b	90.5 ± 2.7 a
	Maxforce HM gel	2.86 (2.70-3.02) c	6.27 (5.94-6.67) a	95.7 ± 4.0 a
Orlando Strain Trial #2	Advion-B 0.1%	0.95 (0.71-1.17) c	8.33 (7.09-10.33) cd	94.2 ± 3.3 ab
	Advion-B 0.5%	0.42 (0.24-0.57) a	4.28 (3.75-5.05) a	98.9 ± 2.1 a
	Advion-B 1.0%	0.55 (0.36-0.74) abc	6.01 (5.19-7.29) bc	98.0 ± 1.7 ab
	Maxforce FC gel	0.87 (0.62-1.12) bc	10.32 (8.41-13.76) d	92.0 ± 2.8 b
	Maxforce HM gel	2.78 (2.62-2.92) d	5.83 (5.55-6.17) b	96.4 ± 2.6 ab
Orlando Strain Trial #3	Advion-C 0.1%	0.78 (0.62-0.92) b	3.15 (2.87-3.50) a	100.0 ± 0.0 a
	Advion-C 0.5%	0.41(0.27-0.56) a	2.91 (2.59-3.31) a	100.0 ± 0.0 a
	Advion-C 1.0%	0.42 (0.29-0.57) a	2.95 (2.62-3.38) a	100.0 ± 0.0 a
	Maxforce FC gel	1.58 (1.33-1.80) c	8.81 (7.69-10.48) c	90.6 ± 3.0 b
	Maxforce HM gel	2.47 (2.31-2.62) d	5.73 (5.41-6.10) b	96.7 ± 3.8 ab

Performance against bait averse cockroaches was rather poor for most gel baits (Figure 2). Both Maxforce FC and hydramethylnon gels had less than 30% final mortality (Table 2). Similarly, all Advion-A and Advion-B gels achieved lower than 60% mortality. Higher levels of indoxacarb improved the gel performance only slightly, as shown with Advion-B gels (Figure 2). Instead, better bait base provided much significant improvement to the bait performance. Advion-C gel containing 0.1% indoxacarb showed excellent efficacy against the bait averse Miami strain cockroaches with 98% final mortality.

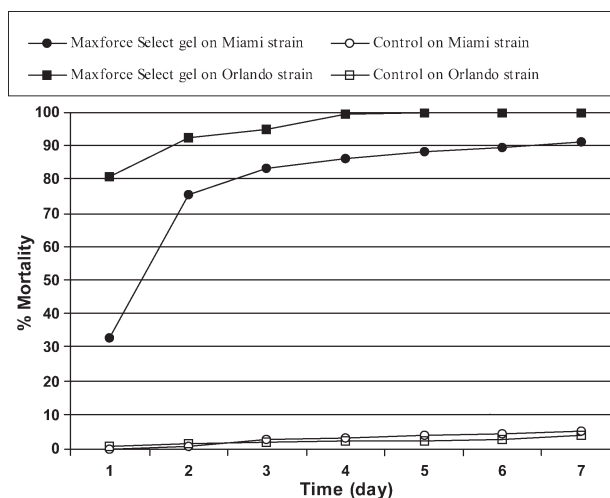


**Figure 2.** Mean mortality of bait averse Miami strain cockroaches under bait treatments. Solid lines are for Maxforce FC gel containing 0.01% fipronil (triangle symbols) and Maxforce gel containing 2.15% hydramethylnon (square symbols). Dashed lines are for Advion gels. Solid line with open circles is control treatment.

**Table 2.** Summary statistics for an efficacy test against bait averse Miami strain cockroaches. All Advion gels contain indoxacarb at the levels indicated. Maxforce FC gel contains 0.01% fipronil and Maxforce HM gel is the Maxforce gel containing 2.15% hydramethylnon. Values followed by the same letter were not significantly different from each other ( $P < 0.05$ ).

Bait Treatment	LT <sub>50</sub> (95% CI) (day)	LT <sub>95</sub> (95% CI) (day)	% Final mortality (Mean ± SEM)
Advion-A 0.1%	11.65 (9.51-15.89) c	45.94 (29.38-93.61) bc	26.4 ± 2.5 d
Advion-B 0.1%	8.46 (6.83-11.91) c	102.63 (49.93-364.53) c	40.5 ± 6.7 c
Advion-B 0.5%	3.87 (3.32-4.50) b	66.28 (36.62-178.22) bc	56.5 ± 7.2 b
Advion-B 1.0%	3.17 (2.60-3.75) b	82.77 (41.02-288.81) c	58.6 ± 6.2 b
Advion-C 0.1%	1.21 (1.04-1.37) a	4.68 (4.32-5.13) a	97.9 ± 1.7 a
Maxforce FC gel	36.44 (19.48-157.02) d	164.76 (57.38-1991.82) c	6.8 ± 2.6 e
Maxforce HM gel	10.12 (8.75-12.51) c	25.66 (19.06-40.28) b	25.6 ± 9.0 d

In a separate experiment, the newly launched Maxforce Select gel was tested against both the Orlando and the Miami cockroaches (Figure 3). It killed 100% of susceptible Orlando cockroaches with LT<sub>50</sub> and LT<sub>95</sub> similar to Advion-C gels containing 0.5% or 1.0% indoxacarb, but better than that containing 0.1%. It was also highly efficacious against the Miami cockroaches with similar LT<sub>50</sub>, but longer LT<sub>95</sub> than Advion-C gel containing 0.1% indoxacarb (Table 2 and 3). Its final mortality was excellent but slightly lower than that of Advion-C containing 0.1% indoxacarb ( $T = 3.14$ ,  $DF = 4$ ,  $P = 0.035$ ) against the Miami cockroaches.



**Figure 3.** Mean mortality of susceptible Orlando strain (square symbols) and bait averse Miami strain cockroaches (circle symbols) treated with Maxforce Select gel containing 0.01% fipronil. Solid symbols represent bait treatments and open symbols represent control treatment.

**Table 3.** Summary statistics on efficacy of Maxforce Select roach gel containing 0.01% fipronil against susceptible Orlando strain cockroaches or bait averse Miami strain cockroaches. Experiment for each cockroach strain was conducted separately with a control.

Cockroaches	LT <sub>50</sub> (95% CI) (day)	LT <sub>95</sub> (95% CI) (day)	% Final mortality (Mean ± SEM)
Orlando Strain	0.35 (0.22 - 0.49)	2.31 (2.03 - 2.63)	100.0 ± 0.0
Miami Strain	0.92 (0.72 - 1.13)	10.28 (9.30 - 11.54)	91.0 ± 4.0

## DISCUSSION

The significance of active ingredients and bait bases on bait performance varied between the strains of cockroaches tested. Against the susceptible Orlando cockroaches, most gel baits examined in this study were highly efficacious no matter what active ingredient and bait base were used (Figure 1). The major difference was that gels containing fipronil and indoxacarb killed faster than the hydramethylnon gel, but the final mortalities for all were very high. It is not surprising that all modern cockroach baits are likely to perform well against susceptible cockroaches given the advancement of bait technologies in the past 20 years.

In contrast, bait base was the determining factor in the bait performance against the bait averse Miami strain cockroaches. Most baits were not efficacious against the Miami cockroaches and only gels with the best bait base, including Advion-C and Maxforce Select gels, performed well (Figure 2 and Table 2). Advion-A and Advion-B gels achieved no more than 60% mortality. Both Maxforce FC and the hydramethylnon gels had mortalities lower than 30% (Figure 2), similar to that previously reported for another bait averse strain (Wang et al., 2004).

The fact that failing gels contained 3 different active ingredients suggests that insecticide resistance is unlikely to be a major reason for the poor bait performance. While there may be some increased tolerance to fipronil (Holbrook et al., 2003), there is no known insecticide resistance to hydramethylnon (Valles and Brenner, 1999) or to indoxacarb. Maxforce hydramethylnon gel was not efficacious against Miami cockroaches even though it was slightly better than Maxforce FC gel containing fipronil (Table 2) in contrast to results obtained against the glucose averse T-164 strain (Silverman and Liang, 2001). In addition, increasing the level of indoxacarb did not improve bait efficacy much, as observed with Advion-B gels (Table 2). Finally, highly effective gels against bait resistant strains could be formulated using the same active ingredient but with different bait bases, as shown with Advion-C gels containing indoxacarb (Table 2) and Maxforce FC Select gel containing fipronil (Table 3). This clearly indicates that bait aversion is the major resistance mechanism for the Miami strains. Indeed, the Miami cockroaches much preferred Purina dog chow over the Maxforce FC gel in contrast with lab susceptible cockroaches (Liang, unpublished data).

Bait aversion as a way to develop resistance to insecticidal bait products was first demonstrated from populations of German cockroaches exhibiting aversion behavior to glucose present in a dry bait matrix containing hydramethylnon (Silverman and Bieman, 1993). Recent developments of control failure mostly involved gel baits with a number of active ingredients (Wang et al., 2004). Most Maxforce dry baits remain palatable to Miami strain cockroaches (Liang, unpublished). While results reported here and in a previous report all pointed to bait aversion as the major cause, its mechanism remains unknown even though sugars may be involved (Wang et al., 2004).

It is important to note that newly developed bait bases may already have bait aversion problems. While it is expected that cockroaches develop bait aversion behavior toward the bait that applies the selection pressure (Rose, 1997), it is not surprising that many bait bases may share one or more common inert ingredients. Wang et al. (2004) found a strain that was resistant to all 4 gel baits tested, including Maxforce FC, Maxforce hydramethylnon, Avert, and Pre-Empt gels, all commercial products. Our results further found that Miami strain even showed bait resistance to proprietary bait formulations (Advion-A and Advion-B) that have never been introduced into the field (Figure 2). As cockroaches continue to evolve under heavy bait selection pressure, the spectra of inert ingredients to which they develop aversion behavior will broaden. Given their ability to develop aversion to glucose, a universal energy source (Silverman and Bieman, 1993), German cockroaches could possibly develop aversion to any inert ingredient. Therefore it is critical that any bait development project should incorporate testing against cockroach strains exhibiting bait aversion behaviors. Changes in cockroach food preference must be continuously monitored and bait formulations continuously updated to maintain baits as an effective tool for cockroach control.

In comparison with fipronil and hydramethylnon, indoxacarb performed similarly or better as a bait active ingredient. The cockroach mortality curves were similar between fipronil and indoxacarb gel baits for both susceptible and bait averse cockroaches (Figure 1 and 2). No repellent or feeding deterrent effects from technical indoxacarb material were observed. An adjuvant associated with indoxacarb in Advion-A and Advion-B gels was found to have some feeding deterrent effects and it also could be responsible for the repellent effects observed earlier (Appel, 2003). Advion-C gels worked extremely well against susceptible cockroaches with 100% mortality. For Miami cockroaches, Advion-C gel containing 0.1% indoxacarb had similar  $LT_{50}$  but better  $LT_{95}$  and final mortality than Maxforce Select gel (Table 2 and 3). While not tested, Advion-C gels containing higher levels of indoxacarb may provide better results to Miami cockroaches. As it works extremely well against both susceptible and bait averse cockroaches, Advion-C gels containing indoxacarb have great potential in cockroach control.



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