DEVELOPMENTAL AND REPRODUCTIVE EFFECTS OF THE INSECT GROWTH REGULATOR, FENOXYCARB, AGAINST THE ORIENTAL COCKROACH, *BLATTA ORIENTALIS* L.

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Abstract—In a laboratory study, groups of third instar *Blatta orientalis* nymphs were reared to adulthood in arenas containing fenoxycarb (48 mg ai/m^2) treated ceramic or plywood tiles. The reproductive capacity of the emergent adults was assessed by pairing each individual with two untreated individuals of the opposite sex. Oothecal production, oothecal hatch and the numbers of nymphs emerging from each hatched ootheca were monitored. Exposure to one-day old deposits of fenoxycarb reduced adult emergence by 45–75% in comparison with an untreated control treatment. Substantial (>35%) mortality also resulted when nymphs were exposed to deposits up to 3.5 months old on plywood, and up to six months old on ceramic. All adult females exposed as nymphs to fenoxycarb failed to reproduce. Untreated females paired with treated males produced several oothecae of normal appearance, but the viability of these oothecae was extremely low with <3% hatching. With strong effects both on the development and reproduction of *B. orientalis*, fenoxycarb is an extremely promising agent for control of infestations of this species.

INTRODUCTION

Fenoxycarb is a member of the juvenile hormone analogue (JHA) group of insect growth regulators (IGRs) and is highly effective as a control agent of many public health insects, including cockroaches, fleas, stored product pests, ants and mosquito larvae (Mulla *et al*, 1985; Banks *et al*, 1988; Marchiondo *et al*, 1990; Reid *et al*, 1990; Edwards *et al*, 1991). Efficacy against cockroaches is particularly high and fenoxycarb has been shown to have activity against all life cycle stages of the German cockroach, *Blattella germanica* (L). Topical application of 10 and 100 g of fenoxycarb results in 76–100% mortality of first through to fourth instar nymphs, with nymphal mortality believed to be the result of ecdysis inhibition (King and Bennett, 1988). The dose required to sterilise adult *B. germanica* following topical application to last instar nymphs is 2.9–4.8 times lower for fenoxycarb than the other JHA developed for cockroach control, hydroprene (King and Bennett, 1989). Exposure to 10 g of fenoxycarb suppresses reproduction in both virgin and fertilized *B. germanica* females, adult males paired with untreated females and inhibits hatchability in four-day old oothecae (King and Bennett, 1990). No such effects occur at the same concentration of hydroprene. The efficacy of fenoxycarb against field populations of *B. germanica* has also been demonstrated (Reid *et al*, 1988; Ogg and Gold, 1988; Brenner *et al*, 1988).

Despite numerous evaluations of IGRs against *B. germanica*, there has been relatively little work done to assess efficacy of these compounds against other major cockroach species. In the UK, the Oriental cockroach, *Blatta orientalis* (L), is a more important pest than *B. germanica* because of its greater prevalence (Alexander *et al*, 1991). *B. orientalis* is often more difficult to control than *B. germanica* because of its ability to survive out of doors throughout the winter (Cornwell, 1968), and because conventional insecticides may degrade before oothecae present at the time of treatment have hatched. These factors have in many cases contributed to the persistence of chronic infestations of this pest in the UK, often despite considerable insecticidal pressure. So far the only IGR evaluated for activity against *B. orientalis* has been hydroprene. The exposure of late instar nymphs to deposits of this compound induces severely deformed genitalia and twisted wings in the emergent adults and strongly impairs reproductive capacity (Bao and Robinson, 1990; Short and Edwards, 1992). Hydroprene therefore shows considerable promise for control of *B. orientalis*, although no field evaluations have as yet been reported.

There exists a definite need for evaluations of other IGRs such as fenoxycarb against *B. orientalis*. This paper reports a laboratory investigation of the activity of fenoxycarb on the development and reproduction of *B. orientalis*, and discusses the likely role this compound may play as a control agent of this species.

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MATERIALS AND METHODS

The cockroaches used in this study were from a laboratory colony of *B. orientalis* which had been in culture at Chesterford Park for approximately twenty years. The strain was originally obtained from a wild population occurring in a London hospital. Cockroaches were maintained on a diet of rolled oats, wheatfeed, fishmeal and yeast (5:5:2:1 by weight), with water provided *ad libitum*. Rearing conditions were 23–26°C, 45–55% r.h. with a photoperiod of 12:12 (L:D).

A 240 g/l EC formulation of fenoxycarb (ethyl 2-[4-phenoxyphenoxy]ethylcarbamate) was applied to the upper surfaces of unglazed ceramic and plywood tiles (15 cm square × 0.5 cm thick), giving a dose of 48 mg ai/m^2. This was carried out using an automated spraying device fitted with a Tee-jet 8004-E nozzle. The nozzle moved at a speed of 1 m/s, at a height of 29.5 cm above the targets and produced an application rate of 40 ml/m^2. Before their use in the study, the treated tiles were aged at 24°C, 50% r.h. for various lengths of time, ranging from one day to twelve months.

Third instar nymphs were removed from the laboratory colony, and in groups of 20–25 (nine only for day 86 assessment), reared to adulthood in arenas containing the treated or untreated tiles. At each age of tile, four groups of nymphs were established (treated ceramic, treated plywood, untreated ceramic and untreated plywood). Each arena consisted of a plastic tray (37 cm length × 24 cm width × 6 cm height), the inner walls of which had been coated with 'Fluon' (polytetrafluoroethylene) to prevent the insects from escaping. A Petri dish containing moist cotton wool and a folded circular paper harbourage (11 cm diameter, placed on the tile) were added to each tray. The tops of all trays were individually sealed with two layers of nylon netting. Every week the mortality of the nymphs in the trays was monitored and all dead individuals removed. Rearing diet and water were supplied *ad libitum* over this period during which environmental conditions were maintained at 24°C, 50% r.h. with a photoperiod of 12:12 (L:D).

The arenas were checked regularly for the emergence of adults and all adults collected were individually placed in plastic holding dishes (11.5 cm diameter × 5 cm height), the inner walls of which had been coated with 'Fluon'. Cockroach rearing diet, moist cotton wool and a folded paper harbourage (7 cm diameter) were provided in each dish and the dishes sealed with a double layer of nylon netting. To assess the reproductive capacity of the adults removed from the arenas, each individual was paired with two untreated adults of the opposite sex taken from the laboratory colony. Adult males were taken directly from the laboratory colony rearing containers whereas, newly-moulted adult females were removed from individual plastic holding pots (5 cm diameter × 7.5 cm height), into which they had been placed as last instars. This ensured that all adult females collected were virgins and had therefore not been inseminated prior to their use in the study. The first four oothecae produced in each dish were collected and individually incubated in plastic pots (5 cm diameter × 7.5 cm height), at 24°C, 50% r.h. All oothecae failing to hatch after an incubation period of 12 weeks were assumed to be non-viable and were discarded. The number of nymphs emerging from each hatched ootheca was recorded.

RESULTS

Survivorship of nymphs through to adulthood was between 65 and 95% when nymphs were reared in arenas containing untreated tiles (Table 1). Exposure to the fenoxycarb-treated ceramic tiles strongly reduced survivorship with no adults emerging from the day 1 assessment, and emergence reduced by 65–75% relative to the control treatment over all three initial assessments up to and including day 86. Thereafter, survivorship increased with adult emergence reduced by 35–45% from arenas containing fenoxycarb-treated ceramic tiles aged three to six months old. Activity of fenoxycarb on plywood was less than on ceramic, with initial emergence reduced by 45%, and no inhibition of emergence apparent when tiles were six months old. Fenoxycarb applied to plywood was probably absorbed deeper into the substratum than occurred on ceramic, so making the compound less available for pick-up by the insects. Fenoxycarb-induced mortality was greatest over the third to fifth instar period and at the time of the final moult to adulthood, when nymphs often failed to shed all segments of the abdominal cuticle. Adults exposed as nymphs to fenoxycarb were commonly of a larger size and darker colour than the untreated controls and all possessed twisted wings. Most females had severely deformed genitalia.

Table 1 Emergence (%) of adult *B. orientalis* following exposure of nymphs to fenoxycarb-treated tiles from the third instar onwards

Treatment	Surface	Age of tiles (days) at start of exposure to nymphs				
		1	21	86	108	176
Untreated	Ceramic	75	75	78	75	95
Untreated	Plywood	70	65	78	90	85
Fenoxycarb	Ceramic	0	5	11	40	50
Fenoxycarb	Plywood	25	20	22	55	85

Table 2 Percentage of adult *B. orientalis* producing normal oothecae following exposure of nymphs to fenoxycarb-treated tiles from the third instar onwards

		Age of tiles (days) at start of exposure to nymphs				
Treatment	Surface	1	21	86	108	176
Treated females × untreated males						
Untreated	Ceramic	88.9*	100	100	100	100
Untreated	Plywood	88.9*	100	100	100	100
Fenoxycarb	Ceramic	—	—	—	0	0
Fenoxycarb	Plywood	0	0	—	0	0
Treated males × untreated females						
Untreated	Ceramic	100	100	100	100	100
Untreated	Plywood	100	100	100	100	100
Fenoxycarb	Ceramic	—	100	100	66.5	100
Fenoxycarb	Plywood	100	100	100	100	85.7

*One female produced only small, deformed oothecae.

Table 3 Percentage of normal oothecae hatching following exposure of *B. orientalis* nymphs to fenoxycarb-treated tiles from the third instar onwards

		Age of tiles (days) at start of exposure to nymphs				
Treatment	Surface	1	21	86	108	176
Treated females × untreated males						
Untreated	Ceramic	50	78.3	66.7	83.5	60
Untreated	Plywood	84.4	84.4	65.2	65.6	54.5
Fenoxycarb	Ceramic	—	—	—	—	—
Fenoxycarb	Plywood	—	—	—	—	—
Treated males × untreated females						
Untreated	Ceramic	71.9	72.7	60	75	67.7
Untreated	Plywood	65	83.3	100	80	78.3
Fenoxycarb	Ceramic	—	8.5	0	0	0
Fenoxycarb	Plywood	0	0	0	0	0

Almost all (>88%) of the untreated × untreated insect pairings resulted in the successful production of normal oothecae (Table 2). The viability of these oothecae was highly variable with between 50 and 100% hatching (Table 3). Between 11 and 15 nymphs typically emerged from the oothecae (Table 4), after an incubation period usually lasting 45–55 days. No adult females exposed to fenoxycarb-treated tiles up to six months old were able to reproduce. All these females were unable to produce either normal oothecae, or the small, deformed, non-viable oothecae which may sometimes be produced by *B. orientalis* females exposed as nymphs to hydroprene (Short and Edwards, 1992). Untreated adult females paired with males exposed to fenoxycarb were able to successfully produce normal oothecae, but the viability of these oothecae was extremely low with only one of 46 hatching. Only one nymph emerged from this ootheca.

Table 4 Mean (±SE) number of nymphs hatching from normal oothecae following exposure of *B. orientalis* nymphs to fenoxycarb-treated tiles from the third instar onwards

		Age of tiles (days) at start of exposure to nymphs				
Treatment	Surface	1	21	86	108	176
Treated females × untreated males						
Untreated	Ceramic	13.4±0.9	12.7±0.7	13.6±0.4	13±0.4	14.1±0.4
Untreated	Plywood	14.4±0.4	13.7±0.4	13.8±0.8	13.3±0.4	12.7±0.6
Fenoxycarb	Ceramic	—	—	—	—	—
Fenoxycarb	Plywood	—	—	—	—	—
Treated males × untreated females						
Untreated	Ceramic	13.4±0.4	11.8±1.2	12.7±1	11.3±1.9	14.2±0.3
Untreated	Plywood	12.7±0.7	13.3±0.7	13.7±0.9	12.9±0.5	11.7±0.9
Fenoxycarb	Ceramic	—	1±0	—	—	—
Fenoxycarb	Plywood	—	—	—	—	—

DISCUSSION

Fenoxycarb at a dose rate of 48 mg ai/m^2 exerted strong effects both on the development and reproduction of *B. orientalis*. The 45–75% reduction in adult emergence occurring for nymphs first exposed to tiles treated 24 h earlier, showed that fenoxycarb induces substantial mortality in this species via tarsal contact exposure. Previous studies involving *B. germanica* have mainly involved treatment of insects by topical application and have also demonstrated high mortality (King and Bennett, 1988). Brenner *et al* (1988) exposed third instar *B. germanica* nymphs to plywood treated with fenoxycarb at 75 mg ai/m^2 and recorded a 44% mortality rate. However, no appreciable mortality resulted when Atkinson *et al* (1992) exposed third instar *B. germanica* nymphs to seven types of surface treated with fenoxycarb at 78.6 mg ai/m^2. Clearly, more evaluations of fenoxycarb activity in tarsal contact tests need to be performed before the situation becomes clear. It would appear from the results presented here that *B. orientalis* is more susceptible to the mortality effect of fenoxycarb than *B. germanica.*

Data on the reproductive biology of the untreated × untreated *B. orientalis* pairings generally showed close agreement with that reported by Short and Edwards (1991), who performed an extensive evaluation of all aspects of the reproductive and developmental biology of this species. Exposure of all female nymphs to fenoxycarb completely inhibited reproduction in these individuals. It was not established whether the females had become inseminated, but given the deformation of the genitalia apparent, it was highly unlikely that these individuals could have mated successfully. Bao and Robinson (1990) reached a similar conclusion when discussing the effects of hydroprene on the morphology of *B. orientalis.*

Despite the production of several normal oothecae, treated male × untreated female pairings gave rise to the emergence of only one nymph, due to the extremely low viability (<3%) of the oothecae. The low viability may have been due to treated males transferring fenoxycarb to the females during mating which may then have affected the subsequent development of the nymphs. The genitalia of treated males appeared less severely affected by fenoxycarb than the females and it is possible that treated males were able to mate. Female sterility due to the transfer of juvenoids from males during mating has been shown to occur in the linden bug, *Pyrrhocoris apterus* L. (Masner *et al*, 1968). An alternative explanation for the low oothecal viability may be that the oothecae were produced by parthenogenetic reproduction. In *B. orientalis,* parthenogenesis is known to result in reduced oothecal viability and nymphal emergence in comparison with sexual reproduction (Short and Edwards, 1991).

The present study has demonstrated long residual activity of fenoxycarb against *B. orientalis.* Although not yet proven for fenoxycarb, it is likely that the sensitive developmental period for induction of reproductive inhibition in *B. orientalis* is the last instar, as is the case with *B. germanica* (Staal *et al*, 1985). With nymphs typically taking at least three months to reach the final instar, and the strong fenoxycarb- induced reproductive effects apparent from exposure to surfaces treated six months earlier, significant levels of fenoxycarb are likely to have been present on the surfaces at least nine months after application. The study is still in progress and as further groups of nymphs are exposed to fenoxycarb deposits more than six months old, the point at which the reproductive effects of fenoxycarb decline, will be determined.

With marked effects both on the development and reproduction of *B. orientalis*, fenoxycarb is an extremely promising agent for control of this species. Fenoxycarb's considerable mortality effect constitutes a major advantage over the activity spectrum of hydroprene which induces little mortality in *B. orientalis* (Short and Edwards, 1992). Long-term field trials will be required to determine the impact of fenoxycarb against established populations of cockroaches. Since use of fenoxycarb on its own will be unlikely to give the rapid decline in insect numbers required by most customers, these trials should, at least initially, evaluate the activity of fenoxycarb in mixture with a conventional insecticide. Thereafter, use of fenoxycarb alone may be sufficient to maintain or improve the suppression of the population induced by the conventional insecticide. Subject to satisfactory performance in field trials against *B. orientalis*, fenoxycarb can be expected to play a major future role in contributing to the control or eradication of long-standing infestations of this pest.

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