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ABSTRACT

There is a need for effective and environmentally sensitive methods of controlling vertebrate pest problems in agriculture and the urban environment. Nonlethal chemical repellents may meet this need where more traditional methods of control, such as scaring, shooting, and trapping, are either ineffectual or unacceptable. One such chemical repellent currently under investigation is cinnamamide, a synthetic compound derived from a plant secondary compound, cinnamic acid. Cinnamamide is unusual because, unlike many of its contemporaries, it deters feeding by both birds and mammals. This paper reviews past and current laboratory and field studies in which cinnamamide is shown to deter feeding by problem birds, such as the woodpigeon *(Columba palumbus)*, rock dove *(C. livia)*, and chestnut-capped blackbird *(Agelaius ruficapillus)*, and mammalian pests, such as the Norway rat *(Rattus norvegicus)*, house mouse *(Mus musculus)*, and European rabbit *(Oryctolagus cuniculus)*. Using peanuts in feeders as a model "crop," we also show that free-living birds (e.g. greenfinch *[Carduela chloris]*, blue tit *[Parus caeruleus]*, and great tit *[P. major]*) are prepared to incur an increased risk of predation or abandon a feeding site

altogether in order to avoid eating food treated with cinnamamide. Laboratory studies of cinnamamide's mode of action suggest that it has both primary (immediate) and secondary (postingestional) activity. Birds generally respond immediately to the compound through unpleasant effects mediated through taste, odor, or irritation of the buccal cavity, whereas some mammals do not find it instantly repellent but learn to avoid it because of its postingestional activity.

KEY WORDS

birds, chemical repellent, cinnamamide, mammals, mode of action, pest control

INTRODUCTION

The quest for benign, environmentally sensitive yet effective means of vertebrate pest management has led to an increased interest in the use of nonlethal chemical repellents. Such compounds are designed to protect a crop from vertebrate damage during its vulnerable periods of development. Contemporary work has focused on naturally occurring compounds and their derivatives, and there are a number that show promise as feeding deterrents against mammals or birds. One such compound is cinnamamide.

Cinnamamide is a synthetic derivative of cinnamic acid, a plant secondary compound. Studies of feeding preferences of the bullfinch *(Pyrrhula pyrrhula)* for flower buds of different pear tree varieties in southeast England revealed an inverse relationship between the palatability of the flower buds and levels of cinnamic acid metabolites (Greig-Smith et al. 1983, Wilson and Blunden 1983, Wilson 1984, Greig-Smith 1985). Subsequent laboratory feeding trials screened a range of naturally occurring and synthetic derivatives of cinnamic acid, and they identified cinnamamide as a potential bird repellent (Crocker and Perry 1990, Crocker et al. 1993*a*).

Cinnamamide was originally identified as an avian repellent, but recent work suggests that it also has activity against mammals and invertebrates. Repellency to both birds and mammals is unusual owing to physiological differences in the chemical senses of these taxa (Kare and Mason 1986). Contemporary, nonlethal, vertebrate repellents, such as methyl anthranilate and capsaicin, have been shown to be repellent to either birds or mammals at a given application rate, but not to both (Glahn et al. 1989, Mason et al. 1992, Mason and Clark 1995). Recent laboratory trials with invertebrate pest species have also shown that cinnamamide (0.5% mass/mass [m/m]) prevented damage to seeds and leaves by field slugs *(Deroceras reticulatum)* (Watkins et al., 1996), grain weevil *(Sitophilus granarius)*, cabbage white caterpillar *(Pieris brassicae)*, and tomato moth caterpillar *(Lacanobia oleracae)* (R. W. Watkins et al., Ministry of Agriculture, Fisheries and Food, UK, unpubl. data).

This paper reviews our current knowledge, based on recent studies and work in progress, of the efficacy of cinnamamide as an avian and mammalian repellent, and discusses its mode of action in both taxonomic groups. We conclude by considering practical field applications for the compound.

CINNAMAMIDE AS AN AVIAN REPELLENT

Cinnamamide was first identified as a putative avian repellent through laboratory studies with the rock dove (Crocker and Perry 1990, Crocker et al. 1993*a*). The rock dove was used as a captive model for the woodpigeon (which does not acclimatize well to captivity), a species which causes significant damage to crops, in particular brassicas, in the United Kingdom (Murton and Jones 1973, Inglis et al. 1989). Further laboratory studies with the rock dove (Watkins et al. 1995) established a dose-response curve which demonstrates that cinnamamide significantly reduces food consumption ($P<0.01$) at concentrations as low as 0.09% m/m of food. The compound's efficacy increases with concentration, and a 94.2% (SE = 1.50) reduction in food consumption is achieved by a concentration of 0.74% m/m (measured concentration 52.4 μmoles/g). This study also showed that the birds' response to cinnamamide changed over the 3 days of the trial. This change was dose dependent: at concentrations <0.26% m/m the birds' response declined over time, whereas it became enhanced at concentrations >0.26%. Cinnamamide has since been shown to reduce food consumption by other captive bird species. In two-choice and short-term no-choice tests, chestnut-capped blackbirds, a significant pest on maturing rice in South America (Pergolani de Costa 1950, Bucher and Bedano 1976), were prevented from eating rice that had been treated with cinnamamide at 0.8% m/m (Gill et al. 1994).

Field studies with wild birds have confirmed cinnamamide's efficacy against a variety of granivorous and omnivorous species. Consumption of pelleted food and seed from feeding stations on the ground and on bird tables by free-living rooks *(Corvus frugilegus)* and chaffinches *(Fringilla coelebs)* declined by >67% when treated with cinnamamide (0.5% m/m application) (Crocker and Reid 1993). In a pilot field trial with autumn-sown oilseed rape *(Brassica napus),* cinnamamide significantly reduced damage by woodpigeons in February and March. This was achieved despite the compound being applied relatively late in the growing season, when the crop had already been damaged, and at an application rate of only 2 kg/ha (Gill et al. 1995).

In order to investigate the efficacy of cinnamamide on free-living birds in terms of the costs that a bird is prepared to incur to avoid eating food treated with the compound, a study using peanuts contained in wire mesh feeders as a model "crop" was designed. Experiments were carried out between January and March, when natural food is relatively scarce, in 1994 and 1995 at a mixed farm in southern England. In both years, peanut feeders were put out on 1.5-m-high posts arranged in 5 rows in a grass field 5, 10, 15, 20, and 25 m from a wooded area. Pretrial observations showed that granivorous and omnivorous birds common in the experimental area, such as blue tit, great tit, greenfinch, coal tit *(Parus ater),* and great-spotted woodpecker *(Dendrocopos major),* fed regularly on the peanuts. All species preferred to feed from the row of peanuts closest to the woods, presumably because feeding farther away from cover carried an increased risk of predation by kestrels *(Falco tinnunculus)* and sparrowhawks *(Accipiter nisus)*, which were common at the experimental site during the study period.

In 1994, the preferred row of peanuts closest to the woodland was treated with cinnamamide (application rate 0.5% m/m). After a brief sampling period during the first hour after treated nuts were put out, all birds avoided these feeders and some left the site altogether, resulting in a reduction in peanut consumption (Figure 1) (Watkins et al. 1994, E. L. Gill et al., Ministry of Agriculture, Fisheries and Food, UK, unpubl. data).

In 1995, the three rows closest to the wooded area were treated with cinnamamide (0.5% m/m application). As in the previous year, birds did not eat the treated nuts; and, during the first day of treatment, some birds flew out >20 m from the woods to feed from the untreated, outer two rows. Intense competition for feeders was observed on these rows and by the second day, nearly all birds had deserted the site, resulting in a reduction in peanut consumption from all rows (Figure 1) (Gill et al., unpubl. data). These experiments not only demonstrate cinnamamide's efficacy against a variety of free-living, granivorous and omnivorous birds, but also show that these birds are prepared to incur an increased cost of predation or abandon the crop altogether rather than consume food treated with cinnamamide. The study also suggests that partial treatment of a crop may be sufficient to deter a pest species or at least to spread the damage to a noneconomic level.

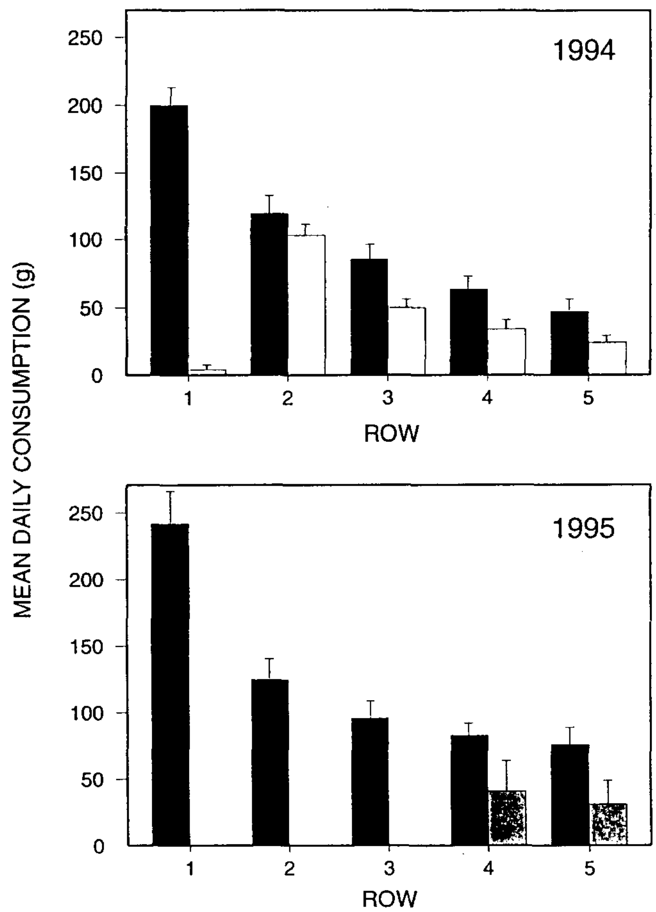

FIGURE 1. Mean daily consumption of peanuts by free-living birds from feeders at different distances from woodland cover: ■ when all rows of peanuts were untreated; □ row 1 (closest to cover) was treated with cinnamamide (1994); rows 1–3 were treated with cinnamamide (1995). Error bars are 1 SE.

CINNAMAMIDE AS A MAMMALIAN REPELLENT

Crocker et al. (1993*b*) showed that cinnamamide (0.5% m/m) can reduce food consumption by laboratory-housed wild rats by >60% over a 3-day no-choice test, although by the third day, there was evidence that the rats were beginning to overcome their aversion to the compound.

Studies are currently being carried out with other mammalian pest species. Food consumption of house mice *(Mus musculus)* was significantly reduced by cinnamamide at a concentration of 0.1% m/m, and this effect increased with concentration. At a concentration of 1.2%, food consumption was reduced by >90% (Gurney et al., 1996). In contrast to the response observed with the rock dove, house mice did not reject cinnamamide immediately, but fed normally during the first 3 hours of the 3-day trial. Consumption of treated food then declined sharply and remained depressed for the duration of the trial. In a pilot study currently being carried out with wild European rabbits held in grassed pens (approximately 25 × 25 m), individuals which would normally eat 300–400 g of carrots overnight barely touched carrots coated in cinnamamide (0.5% m/m application) (I. G. McKillop et al., Minstry of Agriculture, Fisheries & Food, U.K., unpubl. data). By contrast, cinnamamide had little effect on the wood mouse *(Apodemus sylvaticus)*. Although wood mice initially reacted to cinnamamide-treated food (0.8% m/m) in a similar way to house mice by reducing their consumption after 3 hours, this effect did not persist beyond the second morning, and consumption returned to and remained at normal, pretrial levels (Gurney et al., 1996). The reasons behind this remain to be determined. Trials are now in progress to test cinnamamide against two other mammal pests: gray squirrel *(Sciurus carolinensis)* and roe deer *(Capreolus capreolus)*; species which cause significant damage to silviculture and agriculture in Britain.

MODE OF ACTION

Data gathered to date indicate that cinnamamide has a broad spectrum of activity as a vertebrate repellent and that at the same application rate, it can be effective against both birds and mammals. Repellents may be classified as either primary or secondary, according to their site of activity in the target species (Rogers 1980). Primary repellents provoke instantaneous responses through taste, olfaction, or irritation of the buccal cavity. Secondary repellents produce distressing effects after eating (e.g. gastrointestinal malaise or other illness) which, if associated with a novel cue, may cause the subject to develop a conditioned aversion to a given food. Some repellent compounds have both primary and secondary activity. Knowledge of the mode and site of activity of a repellent may permit the development of formulations that target its release to the site of activity (the buccal cavity or upper gastrointestinal tract) and thus optimize its efficacy.

Our studies suggest that the mode of action of cinnamamide differs between birds and mammals. For birds, the data suggest that the compound has an immediate, primary effect: observations in the laboratory and field have shown that birds find the compound immediately distasteful (Crocker and Reid 1993; Gill et al. 1994; Watkins et al. 1995; Gill et al., unpubl. data). This primary effect has been confirmed for rock doves by masking the taste and smell of cinnamamide at ingestion by encapsulating microspheres of the compound in a cationic, waterpermeable resin which breaks open and releases the compound in the crop (Nadian et al. 1993; subject of patent application). When cinnamamide was presented in this formulation on pelleted food (0.65% m/m) in a 3-day no-choice test, the doves' food consumption did not differ between treated and untreated food, suggesting that it was the taste or odor of the cinnamamide which deterred the birds from eating it and not a postingestional effect (Watkins et al. 1994). However, the existence of a postingestional, secondary effect in addition to the primary effect cannot be completely discounted for birds. Chestnut-capped blackbirds which sampled treated rice grains in a no-choice test showed behavioral signs of malaise, such as fluffed feathers and abnormally quiet behavior, for about 5 minutes following ingestion (Gill et al. 1994). In addition, as noted above, rock doves that received food treated with cinnamamide at concentrations >0.26% increased their rejection of food over the 3-day trial (Watkins et al. 1995), suggesting that adversion was related to their previous day's experience, possibly through a postingestional effect.

By contrast, house mice showed a delayed response to cinnamamide (Gurney et al., 1996), suggesting that they did not find the compound immediately distasteful but postingestional effects caused them to reject it subsequently. This response is now being investigated further, and preliminary results suggest that cinnamamide generates a powerful conditioned taste aversion response in house mice (Watkins et al., in press). However, the response of the house mice may not be typical of all mammals. The response of rats to cinnamamide appeared to decline over the 3 days of the trial (Crocker et al. 1993*b*). Rabbits hardly sampled treated carrots and, on first sniffing, some individuals were seen to jump away from the carrots as if frightened (Gill, pers. obs.).

In summary, cinnamamide can induce both primary and secondary effects in vertebrates. The data suggest that birds generally respond to the compound immediately, whereas some mammals do not find it instantly repellent but respond to its secondary activity after ingestion—a response which may promote a conditioned taste aversion. Future work with squirrels and deer should provide us with more information on the mode of action of cinnamamide in mammals.

MANAGEMENT IMPLICATIONS

With its broad spectrum of activity and similar effective dose-response characteristics for birds and mammals, cinnamamide has great potential for use in the management of problems involving both classes of vertebrates—preventing damage to crops and consumption of toxic products by nontarget wildlife. The immediate response to the compound noted for birds and some mammals suggests that for field applications, cinnamamide should be formulated so that its taste and odor are not masked. However, if it is proven that the compound can induce a conditioned taste aversion in some species, for such applications its taste and odor must be masked so that the target species associates the taste of the target food with malaise and not that of cinnamamide.

A compound that has the potential to reduce damage by a broad range of species could be a most valuable wildlife management tool but, as is the case for all repellents, efficacy in the field will ultimately depend not only on the compound's potency and formulation but also on the nature and availability of alternative food sources. As such, its potency may be best optimized when employed along with other pest management techniques in an integrated pest management scheme (Feare 1995).

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