8-1-1995

# Effectiveness of Capsaicin as a Repellent to Birdseed Consumption by Gray Squirrels

Christopher S. Fitzgerald
*Cornell University*

Paul D. Curtis
*Cornell University*, pdc1@cornell.edu

Milo E. Richmond
*Cornell University*

Joseph A. Dunn
*Snyder Seed Corporation*

16

# Effectiveness of Capsaicin as a Repellent to Birdseed Consumption by Gray Squirrels

**Christopher S. Fitzgerald,** New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, Cornell University, Ithaca, NY 14853
**Paul D. Curtis,** Cornell Cooperative Extension, Department of Natural Resources, Cornell University, Ithaca, NY 14853
**Milo E. Richmond,** New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, Cornell University, Ithaca, NY 14853
**Joseph A. Dunn,** Snyder Seed Corporation, West Amherst, NY 14228

## ABSTRACT

We evaluated the efficacy of capsaicin as an aversive agent to captive and free-ranging gray squirrels *(Sciurus carolinensis)*. Capsaicin appeared more aversive in lipid-based formulations. Sunflower hearts treated with capsaicin oleoresins at 100,000 Scoville Heat Units (SHU's) demonstrated near-complete aversiveness to captive squirrels. These treatments were sampled by food-deprived captive squirrels, but were not consumed due to their extreme pungency. Additionally, capsaicin-treated suet was very effective at lower concentrations than was observed with seeds (24,000 SHU-suet versus 100,000 SHU-seed). Three ground-pepper treatments (A = 8,250 SHU's, B = 27,500 SHU's, and C = 82,500 SHU's) offered simultaneously with control seeds to free-ranging squirrels revealed a dose-dependent aversive response. These same three treatments (A, B, and C) on sunflower hearts with control hearts available were also avoided by free-ranging squirrels; however, there was no significant differences ($P>0.05$) in mean consumption between the capsaicin levels. Apparently, even low capsaicin concentrations (8,250 SHU's) are as aversive as higher concentrations (27,500 to 82,500 SHU's) when applied directly to sunflower hearts.

## KEY WORDS

*capsaicin, gray squirrel, Sciurus carolinensis, irritation, birdseed*

## INTRODUCTION

The annual expenditure for birdseed in the United States is over $2 billion. Burton (1992) reported that more than one-third of the U.S. population feeds birds in some form. Eastern gray squirrels *(Sciurus carolinensis)* dominate and often damage bird feeders supplied with sunflower seeds and hearts, and birdseed mixes (Adler 1988, Burton 1992). People who feed birds use an endless variety of techniques to prevent squirrels from dominating their feeders. Most of these techniques are largely unsuccessful, and some extreme methods (e.g., shooting, trapping, and poisoning) are potentially hazardous to nontarget organisms, unlawful, or unacceptable in residential areas. For these reasons, it has become important to identify an environmentally sound and legal aversive agent to reduce consumption of birdseed by squirrels.

Capsaicin, the naturally pungent component in peppers of the genus *Capsicum*, has been used as a repellent against mammalian wildlife damage to orchards, nurseries, gardens, and ornamental plantings (Swihart and Conover 1991, Andelt et al. 1994). It is capsaicin that gives peppers their "hot" sensation when consumed by mammals, as this compound binds to specific high-affinity receptors on C-afferent fibres (Szolcsanyi 1976, Nagy 1982, Nutrition Reviews 1986), inducing a neuronal response that may also have efferent neuron actions in peripheral tissues (Bevan and Szolcsanyi 1990). Birds do not sense this effect because they either lack the receptors specific to capsaicin binding (Mason and Maruniak 1983, Geisthovel et al. 1986), or have receptors that are insensitive to capsaicin (Szolcsanyi et al. 1986). Subcutaneous injections of capsaicin in red-winged blackbirds *(Agelaius phoeniceus)* were found to disrupt heat discrimination and thermoregulation, but had no effect on oral and topical sensitivity (Mason and Maruniak 1983). Additionally, the nociceptive threshold doses for pigeons *(Columba livia)* and chickens *(Gallus gallus)* were found to be 3–4 orders of magnitude greater than in guinea pigs *(Cavia* sp.) (Szolcsanyi et al. 1985). As with other fruits, pepper seeds are dispersed by vertebrate herbivores. The fact that some birds (e.g., parrots) are known to regularly consume hot peppers while nonhuman mammals do not, suggests *Capsicum*'s adaptation/coevolution to long-distance seed dispersal via Capsicum-insensitive avian species (Mason and Maruniak 1983).

It was our objective to determine capsaicin's efficacy as a deterrent to birdseed consumption by squirrels at different concentrations and in different formulations. The hottest pepper known to exist is the habanero at 500,000 Scoville Heat Units (SHU's) (Chile Pepper Institute 1994) while pure capsaicin is 16,500,000 SHU's. An SHU is the traditional measure of the pungency of hot peppers and is quantified as the number of dilutions required to minimize detection of the "heat" sensation. Capsaicinoids are the heat-producing compounds in *Capsicum*, which contribute to the overall SHU or concentration (Hoffman et al. 1983). We hypothesized that higher concentrations of capsaicin would deter squirrels more effectively than lower concentrations.

## METHODS

Squirrels were live-trapped near the Cornell University Campus in Ithaca, NY, and housed singly in 1.8- × 1.8- × 1.8-m (6 × 6 × 6 ft) outdoor cages. Cages were constructed of poultry wire covering metal frames, and each contained a nest box and climbing limbs. Two stainlesssteel food hoppers were mounted on each cage allowing animals to be fed from outside of the cages, thereby minimizing disturbance of the squirrels.

An acclimation period of at least 10 days was provided for each squirrel prior to the onset of experimentation. Each squirrel was housed for a period of 1 to 3 months, during which time they participated in various feeding trials. After experimentation, squirrels were marked and released at initial capture sites. An individual marking scheme allowed us to follow movements and survival as well as to avoid recapture and reuse of released squirrels. Fifty-five squirrels were captured and housed for experimentation between August 1994 and February 1995.

Each squirrel was provided with water, whole apples, ear corn, peanuts, sunflower seeds, and commercial rodent food ad libitum prior to and following all feeding trials. Whole gray-striped sunflower seeds, sunflower hearts, and suet dough were used in efficacy trials because these are the foods most commonly provided at bird feeders singly or in seed mixes (Adler 1988, Burton 1992). All food was weighed on an electronic balance (Acculab, Newtown, PA) before feeding, and food remaining after the test period was collected and reweighed to determine consumption. Using the mounted food hoppers, feeding trials consisted of choice (two food types offered) and no-choice (one food type offered) as in similar repellency studies (Brugger 1992, Jakubas et al. 1992). During choice-feeding trials, the two food items were alternated between the front and rear food hoppers to avoid habituation. Prior to each trial, food was removed for approximately 12 hr so that food-deprived (hungry) squirrels were the experimental subjects.

In addition to captive-squirrel experimentation, feeding studies were conducted with free-ranging squirrels using wooden platform feeders constructed of plywood boards on 15-cm (6 in) wooden legs. Platforms were divided into four equal compartments with strips of wood. Platform feeders provided multiple choices with two or four food items presented in separate compartments. Free-ranging squirrels always had the option to feed on natural foods.

Ground-pepper powder and oleoresin of *Capsicum* were analyzed for capsaicinoid content with high-pressure liquid chromatography (HPLC) by the spice manufacturer (McCormick & Co., Hunt Valley, MD). Capsaicinoid content was then used to calculate an estimated SHU dosage (Hoffman et al. 1983). All treatment formulations were prepared by a seed manufacturer (Snyder Seed Corp., West Amherst, NY) by mixing varying proportions of food and capsaicin. The pepper was bound to seeds with a tapioca-based dextrin "glue" (Crystal Gum, National Starch Company, Charlotte, NC). Capsaicin applications did not penetrate sunflower seed hulls, so treated whole seeds contained untreated hearts. Preliminary feeding trials demonstrated no preference between glue-coated seeds and control seeds.

Ground-pepper offerings included Treatments A (8,250 SHU's), B (27,500 SHU's), and C (82,500 SHU's) using whole sunflower seeds and sunflower hearts separately. Initially, 3 milder ground-pepper treatments (275 SHU's, 825 SHU's, 2,750 SHU's) were also tested; however, no aversion was observed, so they were omitted from subsequent experimentation. The highest ground-pepper treatment that we could produce was 82,500 SHU's, as there was a limit to the amount of pepper that could be bound to the seed with the dextrin glue. For this reason, oleoresins were produced by distilling *Capsicum* powder in a solvent and then evaporating the solvent. We tested a single oleoresin concentration of 100,000 SHU's.

## Cage Trials

### *Experiment 1*

To determine the aversiveness of ground-pepper treatments, a no-choice trial was conducted with 25 g (less than one-half of the daily ration) of 1 of 6 sunflower heart treatments (275 SHU's, 825 SHU's, 2,750 SHU's, 8,250 SHU's, 27,500 SHU's, 82,500 SHU's) offered per day for 3 consecutive days (*n* = 18 squirrels). Each treatment was offered to three squirrels. After this experiment, we omitted the 3 mildest treatments from subsequent trials because all were completely consumed. All further ground-capsaicin experiments included treatments A (8,250 SHU's), B (27,500 SHU's), and C (82,500 SHU's).

### *Experiment 2*

To determine the aversiveness of dilute oleoresin of *Capsicum*, a no-choice trial was conducted with 20 g (approximately one-fourth of the daily winter ration) of treated hearts (Treatment O = 100,000 SHU's) offered per day for 3 consecutive days (*n* = 17 squirrels). Hearts were used instead of whole seeds so that all food consumed was certain of containing hot pepper.

### *Experiment 3*

We examined the efficacy of capsaicin-treated suet by offering 40 g/day (approximately one-half of the daily fall–winter ration) of treated suet with 40 g/day of control sunflower seed for 4 days with 16 squirrels. Four different suet formulations were tested: control, X (6,000 SHU's), Y (12,000 SHU's), and Z (24,000 SHU's).

## Field Trials

### *Experiment 1*

We evaluated the efficacy of ground capsaicin for free-ranging squirrels by offering 150 g of each whole-seed treatment (control, A = 8,250 SHU's, B = 27,500 SHU's, C = 82,500 SHU's) in platform feeders for 3 hr (*n* = 14 replicates). All seed remaining was removed from feeders and weighed to calculate the amount of each treatment consumed.

### *Experiment 2*

Experiment 1 was repeated using sunflower hearts instead of whole seeds. The same treatments were offered (A, B, and C) for 3 hr in platform feeders (*n* = 18 replicates).

### *Experiment 3*

To further identify the efficacy of each whole-seed treatment (A, B, and C) on free-ranging squirrels, platform feeders containing 150 g of control and 150 g of a single treatment (A, B, or C) were placed outside for 3 hr ($n$ = 12 replicates for each treatment).

### *Experiment 4*

Experiment 3 was repeated substituting sunflower hearts for whole seeds. Again, 150 g of control hearts and 150 g of a single treatment (A, B, or C hearts) were offered for 3 hr ($n$ = 12 replicates for each treatment).

Data were analyzed as mean grams of food consumed for each treatment using ANOVA models (Abacus Concepts 1989). We used Fisher's protected least significant difference test (Steel and Torrie 1980:176) to separate means when the overall $F$-test indicated treatment effects ($P<0.05$). Experimental data for free-ranging squirrels were analyzed as mean grams consumed per hour, whereas captive-squirrel data were analyzed as mean grams consumed per 24 hr.

## RESULTS

Both cage and field trials elicited highly uniform feeding behavior. In cage trials, squirrels immediately detected a difference between treated and control foods, moved directly to the control hopper, and consumed all available food before sampling the treated offering. Field trials were similar as squirrels approaching feeding platforms moved directly to the control seed and sat in or adjacent to that compartment. Other treatments were left untouched except when an interloper took seeds from the section farthest from the control. Also, squirrels that fed on treated seeds displayed obvious irritation by face-washing, muzzle-rubbing, excessive blinking, and circling behavior.

### Captive Trials

### *Experiment 1*

On day 1 of this no-choice trial (Figure 1), mean consumption of the 82,500-SHU treatment (6.57 g) was significantly lower ($F$ = 4.77, $P$ = 0.01) than that of all other offerings (19.8–25.0 g). By day 2, there was no significant difference ($F$ = 1.10, $P$ = 0.41) in mean consumption among offerings, though consumption of the 82,500-SHU treatment remained lower than that of the others each day.

### *Experiment 2*

During the 3 days of this no-choice trial, mean daily consumption of Treatment O (100,000 SHU oleoresin-treated sunflower hearts) by the 17 squirrels tested never exceeded 0.5 g, and the

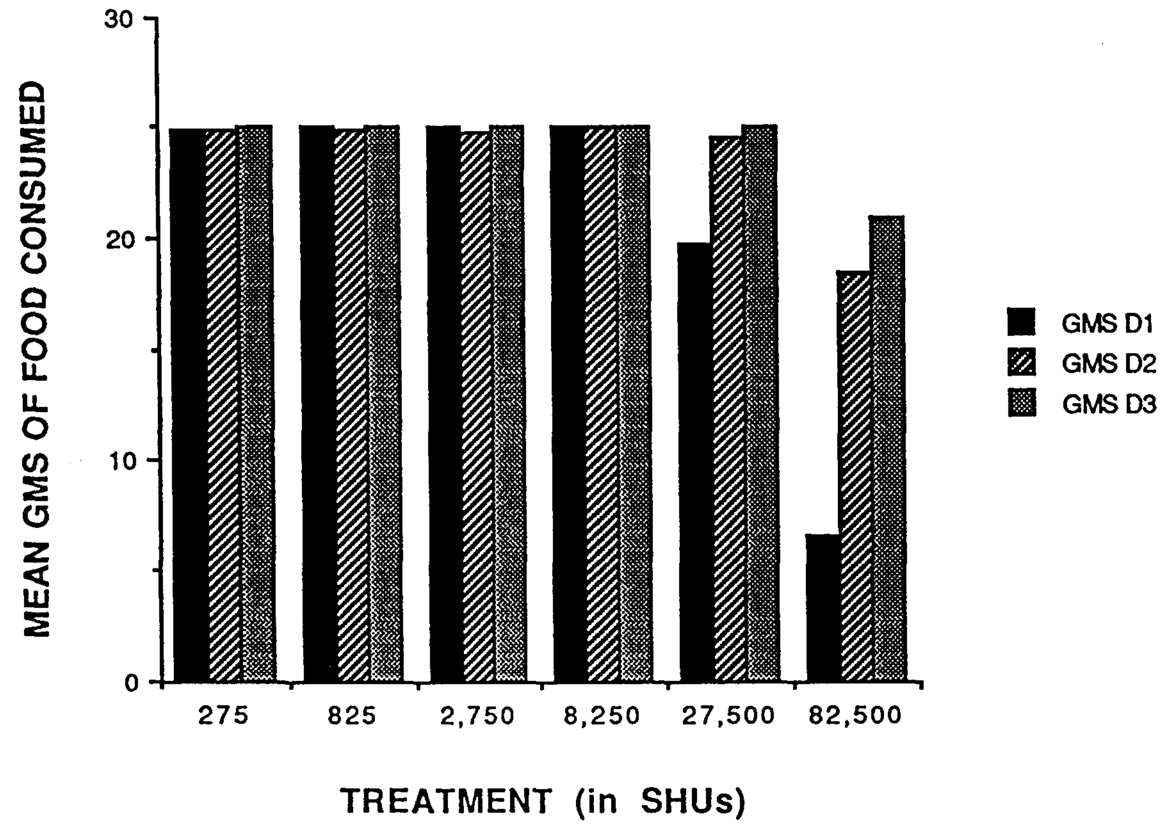


**FIGURE 1.** Cage Experiment 1: No-choice feeding trial with captive squirrels, Ithaca, NY, September 14–16, 1994. Squirrels ($n$ = 18) were offered 25 g/day of one of six different ground-capsaicin treatments on sunflower hearts for 3 consecutive days. Each treatment was offered to three different squirrels. A Scoville Heat Unit (SHU) is the traditional measure of pungency in hot peppers, calculated by quantifying the percent capsaicinoid with high-pressure liquid chromatography. The 3 mildest treatments (275 to 2,750 SHU's) were not used further; and the remaining 3 treatments were labeled as A = 8,250 SHU's, B = 27,500 SHU's, and C = 82,500 SHU's.

mean daily consumption for the entire trial was 0.2 g. High concentrations of capsaicin can provide a near-complete barrier to food intake for extremely hungry squirrels.

*Experiment 3*

For the first 2 days of this trial, the only significant differences (Day 1: $F = 6.33$, $P < 0.01$; Day 2: $F = 20.0$, $P < 0.001$) in mean consumption were observed between control sunflower seed and suet treatments (Figure 2). No significant difference in mean consumption was observed among individual suet treatments (X = 6,000 SHU's, Y = 12,000 SHU's, Z = 24,000 SHU's) until day 3. On day 3, mean consumption of control seed (34.4 g) and X (30.5 g) were

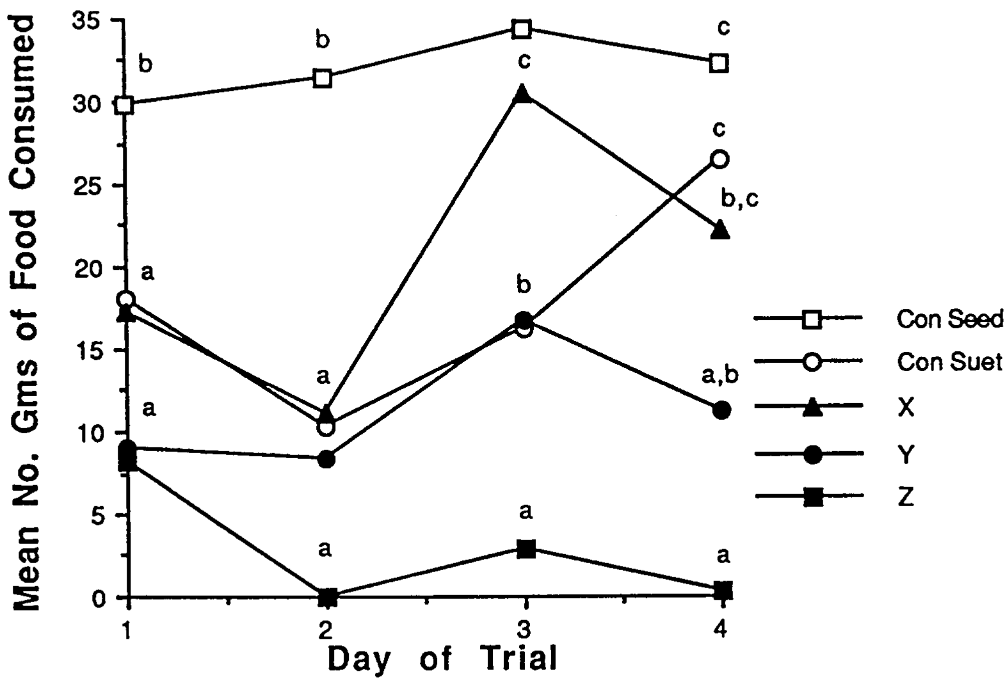


**FIGURE 2.** Cage Experiment 3: Feeding trial with capsaicin-treated suet offered to captive squirrels, Ithaca, NY, January 5–8, 1995. Squirrels ($n$ = 16) were offered 40 g of sunflower seeds along with 40 g of one of four suet types (control, X = 6,000 SHU's, Y = 12,000 SHU's, Z = 24,000 SHU's) for 4 consecutive days. Daily means labeled with the same letters (a,b,c) are not significantly different at $P$ = 0.05. A Scoville Heat Unit (SHU) is the traditional measure of pungency in hot peppers, calculated by quantifying the percent capsaicinoid with high-pressure liquid chromatography.

significantly greater ($F$ = 14.40, $P$<0.001) than mean consumption for all other offerings. On day 4, no significant difference in mean consumption was observed among control seed (32.2 g), control suet (26.4 g), and X (22.2 g); however, mean consumption of all of these was significantly greater ($F$ = 12.24, $P$<0.001) than that of Treatment Z. After day 1, mean consumption of Treatment Z was never greater than 4 g.

## Field Trials

### *Experiment 1*

The mean grams of control seed consumed (25.9 g/hr) by free-ranging squirrels was significantly greater ($F$ = 113.47, $P$<0.001) than that of all other treatments (A = 2.3 g/hr, B = 1.2 g/hr, C = 0.8 g/hr). There was no significant difference in mean consumption among the three seed treatments (A, B, and C) or in mean consumption during the 6 days of experimentation (Figure 3).

### *Experiment 2*

Mean consumption of control hearts (52.9 g/hr) was significantly greater ($F$ = 62.15, $P$<0.001) than that of all other heart treatments offered simultaneously (control versus A, B, and C). Mean consumption of A and B were not significantly different (9.5 g/hr and 11.1 g/hr, respectively), and neither were A (9.5 g/hr) and C (2.5 g/hr, Figure 4). It became apparent that consumption of B was consistently greater than that of A, though not significantly so. We surmised that this slight difference in consumption of Treatment B was due to dominant animals occupying and defending the control section as well as the adjacent sections. When the locations of B and C in the platform feeders were switched (n = 3) so that B was adjacent to the control and C was opposite (farthest from) the control, a dose-dependent response was observed. Mean consumption was 66.5 g/hr (control), 26.3 g/hr (A), 11.5 g/hr (B), and 0.9 g/hr (C) with consumption of B and C significantly lower ($F$ = 46.27, $P$<0.001) than that of A, and consumption of A significantly lower than that of the control.

### *Experiment 3*

Mean consumption exhibited a predictable, dose-dependent response from control through Treatment C (Figure 5). For this paired test (control seed versus single treatments), mean grams of seed consumed by free-ranging squirrels was significantly different ($F$ = 33.49, $P$<0.001) among all treatments (control = 27.2 g, A = 18.4 g, B = 8.7 g, and C = 1.2 g).

### *Experiment 4*

Mean grams of control hearts consumed (44.9 g/hr) by free-ranging squirrels was significantly greater ($F$ = 125.62, $P$<0.001) than that for all three treated hearts (A = 10.2 g/hr, B = 8.9 g/hr, and C = 6.6 g/hr) in these paired offerings (control hearts versus single treatments). No significant difference was found between pepper treatments (Figure 6).

## DISCUSSION

Preliminary trials with treated seed mixes demonstrated that squirrels did not eat all of the seed types present in mixed birdseed, but consumed only sunflower seeds and hearts. No preference was observed between control sunflower seeds and those coated with the tapioca-based glue, indicating that squirrels did not find that treated seeds were more palatable than controls based on the glue application.

Initial experimentation with capsaicin-treated sunflower seeds indicated little reduction in consumption by captive squirrels, although some aversiveness was observed. Squirrels always consumed controls before sampling treated foods when offered a choice. Furthermore, captive

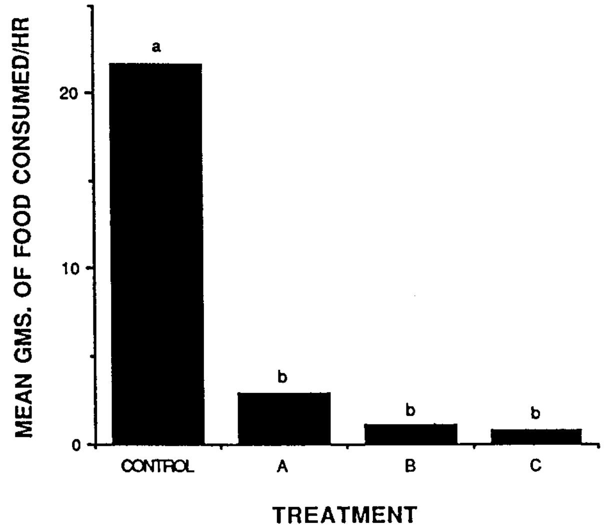


**FIGURE 3.** Field Experiment 1: Feeding trial with free-ranging squirrels, Ithaca, NY, November 22–December 9, 1994. Squirrels were offered 150 g of control sunflower seeds, plus 150 g of each of three capsaicin treatments (A = 8,250 SHU's, B = 27,500 SHU's, C = 82,500 SHU's) for a total of 600 g. Trials were conducted on six different days during the experimentation period. Means labeled with the same letters (a,b) are not significantly different at $P = 0.05$. A Scoville Heat Unit (SHU) is the traditional measure of pungency in hot peppers, calculated by quantifying the percent capsaicinoid with high-pressure liquid chromatography.

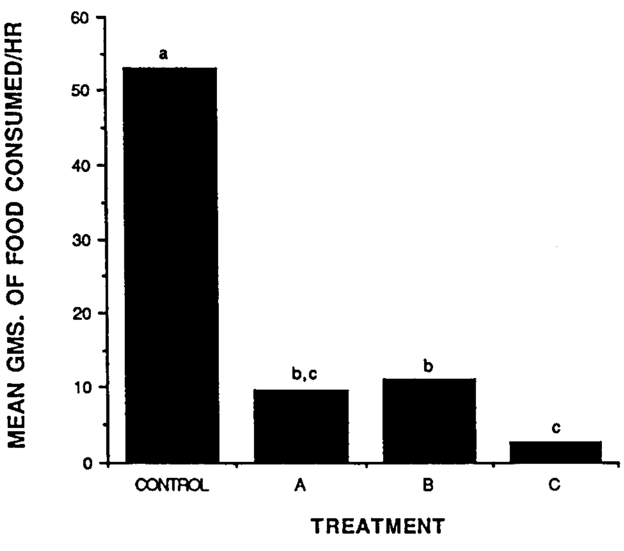


**FIGURE 4.** Field Experiment 2: Feeding trial with free-ranging squirrels, Ithaca, NY, February 4–7, 1995. During each 3-hr trial ($n = 18$), squirrels were offered 150 g of control sunflower hearts, along with 150 g of each of three capsaicin treatments (A = 8,250 SHU's, B = 27,500 SHU's, C = 82,500 SHU's) for a total of 600 g. Means labeled with the same letters (a,b) are not significantly different at $P = 0.05$. A Scoville Heat Unit (SHU) is the traditional measure of pungency in hot peppers, calculated by quantifying the percent capsaicinoid with high-pressure liquid chromatography.

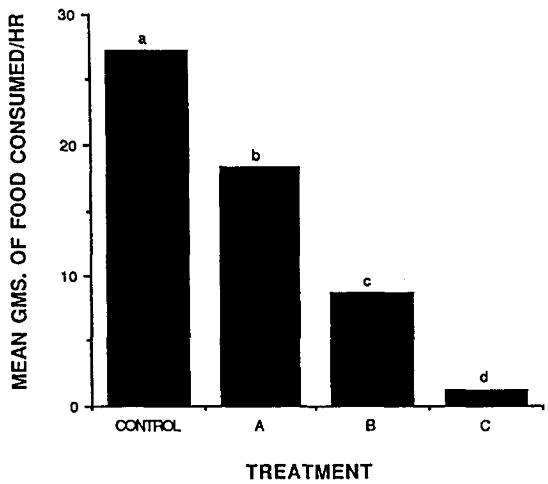


**FIGURE 5.** Field Experiment 3: Feeding trial with free-ranging squirrels, Ithaca, NY, January 19–27, 1995. Each 3-hr bout ($n$ = 12) consisted of a choice between 150 g of control sunflower seeds and 150 g of one of three levels of capsaicin-treated sunflower seeds (A = 8,250 SHU's, B = 27,500 SHU's, C = 82,500 SHU's). Means with different letters (a,b,c,d) are significantly different at $P = 0.05$. A Scoville Heat Unit (SHU) is the traditional measure of pungency in hot peppers, calculated by quantifying the percent capsaicinoid with high-pressure liquid chromatography.

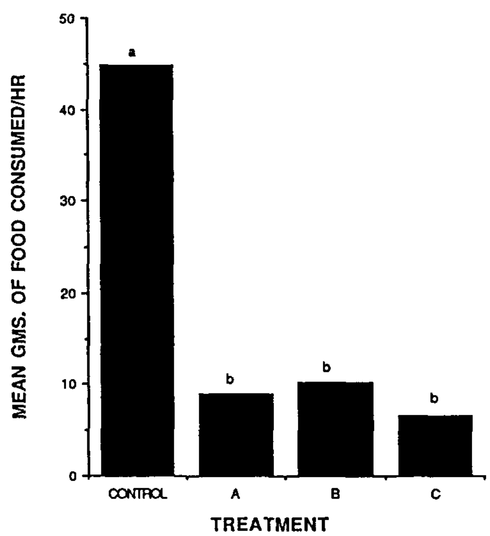


**FIGURE 6.** Field Experiment 4: Feeding trial with free-ranging squirrels Ithaca, NY, January 1995. Each 3-hr bout ($n$ = 12) consisted of a choice between 150 g of control sunflower hearts and 150 g of one of three levels of capsaicin-treated sunflower hearts (A = 8,250 SHU's, B = 27,500 SHU's, C = 82,500 SHU's). Treatment means with the same letters (a,b) are not significantly different at $P = 0.05$. A Scoville Heat Unit (SHU) is the traditional measure of pungency in hot peppers, calculated by quantifying the percent capsaicinoid with high-pressure liquid chromatography.

squirrels were observed rubbing their mouths on nestboxes, limbs, and the ground after consuming treatments. These behaviors indicated that treated seeds were less palatable than controls.

Additionally, Treatment C (82,500 SHU's) displayed significant aversiveness at the onset of Cage Experiment 1. However, after 1 to 2 days, consumption of this high-capsaicin concentration was similar to that for milder treatments (Figure 1), perhaps due to squirrel hunger or increased tolerance.

Capsaicin-treated suet (Figure 2) effectively reduced consumption by squirrels at far lower concentrations than with treated seed when control foods were present. The 24,000-SHU suet (Z) was virtually untouched by 4 squirrels for 4 consecutive days (Figure 2). The greatest consumption of suet Z occurred on day 1, as squirrels sampled the suet without fully consuming it. Squirrels were observed taking a chunk of suet from the feeders and tasting it. However, those chunks were never completely eaten, remained crumbled on the cage floors, and were, therefore, lost from the sample weight.

Although consumption of suet by squirrels is not a noticeable problem (perhaps due to "squirrel-resistant" suet feeders), it is worth noting the efficacy of treated suet and the relatively low concentration at which the aversion occurred. Both capsaicin oleoresins and suet treatments were lipid-based formulations. The oleoresin contains the essential *Capsicum* oils and suet is mostly animal fat. Capsaicin's long side chain (lipophilicity) is one of several factors that may correlate positively with mammalian irritancy (Mason et al. 1991). Capsaicin may be more aversive to squirrels when coupled with a lipid carrier.

Free-ranging squirrels (Figures 3–6) exhibited a more noticeable aversion to ground-pepper treatments than that observed for captive squirrels (Figure 1). In captivity, food-deprived squirrels were offered only small rations, and chose to eat at least some of the capsaicin-treated food when hungry. Conversely, free-ranging squirrels could forage on natural foods elsewhere if experimental offerings were unpalatable. Thus, field trials more closely simulated the conditions at backyard feeders than did the cage trials. However, both experimental settings proved valuable in identifying capsaicin's efficacy. Caged squirrels tolerated ground-pepper treatments up to 82,500 SHU's (Figure 1). Because some treatments (O = 100,000 SHU oleoresin, and Z = 24,000 SHU suet) were untouched even in cage trials, an upper threshold for capsaicin concentration was demonstrated (Figure 2).

With free-ranging squirrels, social behavior affected consumption of birdseed at feeders. For example in Field Experiment 2, treated hearts were arranged clockwise from control to C, with B directly opposite the control. It became apparent that consumption of Treatment B was regularly greater than that of A, though not significantly so. When the locations of B and C were switched, the average consumption was more predictable, supporting our hypothesis that dominant individuals guarded control and adjacent sections while feeding.

If only one food item were offered at a feeder, squirrels were likely to consume some of it, even if it were treated with high levels of ground capsaicin (e.g., C = 82,500 SHU's). However, when capsaicin treatments were offered at outdoor feeders with control seed, consumption of treatments was significantly lower than that of untreated control offerings (Figures 3–6). Apparently capsaicin's efficacy for reducing consumption of birdseed by squirrels was greatest when more palatable foods were available.

In addition to the number of food choices, the aversiveness of treatments was also influenced by the food type (whole seed versus hearts). Squirrels opened treated whole seeds and consumed the enclosed untreated hearts with minimal oral membrane exposure to capsaicin. However, when treated sunflower hearts were offered, consumption involved direct capsaicin contact with oral mucous membranes. In Field Experiments 2 and 4 (Figures 4 and 6), there was no difference in average consumption among capsaicin treated hearts. However, in Field Experiment 3 (Figure 5), mean consumption of whole-seed treatments exhibited a dose-dependent response, with consumption of each successive concentration significantly lower than the preceding treatment. The fact that there was no difference in consumption between heart treatments in Field Experiments 2 and 4 indicated their near-equal aversiveness. Each of the heart treatments was sampled by several squirrels and not substantially consumed by any.

Aversive responses may have been partly due to the amount of volatile pepper dust squirrels experienced while feeding. Treatment C (82,500 SHU's) was more heavily coated with pepper than were A or B; and, therefore, capsaicin dust was more likely to make contact with sensitive areas (e.g., lips, tongue, eyes, and nose).

The treatment that exhibited near-complete aversiveness in no-choice offerings was the oleoresin-treated sunflower hearts (O = 100,000 SHU's). Additionally, capsaicin-treated suet demonstrated almost complete suppression of feeding by captive squirrels at a relatively low concentration (24,000 SHU's). Capsaicin apparently exhibited increased efficacy when coupled with a lipid carrier.

One problem we encountered during this study was the lack of uniformity in quantifying capsaicin heat strengths reported in the literature. Other wildlife-repellency studies (Swihart and Conover 1991, Andelt et al. 1994) reported capsaicin treatments as percent concentrations, whereas we expressed our treatments in Scoville Heat Units. This difference made comparisons between studies difficult and highlighted the need for a suitable conversion.

According to Todd et al. (1977), the pungency of a given sample can be estimated by determining the capsaicin content with HPLC, and subsequently multiplying that value by the pungency of pure capsaicin (16,500,000 SHU's), which has been previously reported (Suzuki et al. 1957, Todd 1958, Dewitt and Gerlach 1990). This standard value for pure capsaicin was multiplied by the percent concentrations reported in other repellency studies to determine comparative SHU's for those treatments. For example, Hot Sauce Animal Repellent® (Miller Chemical and Fertilizer Company, Hanover, PA) is distributed at a 2.5% concentration or 412,500 SHU's ($0.025 \times 16{,}500{,}000$). Therefore, the 0.062 (labeled rate), 0.62, and 6.2% concentrations of Hot Sauce tested by Andelt et al. (1994) would be equivalent to 256 SHU's, 2,558 SHU's, and 25,575 SHU's, respectively. In that study, the 6.2% concentration of Hot Sauce (0.155% capsaicin) was the most effective repellent. In our cage trials, some aversiveness was exhibited by captive squirrels at the 27,500 SHU concentration (0.167% capsaicin). However, consistent repellency was not observed until sunflower hearts were treated with 100,000-SHU oleoresins (e.g., a 0.61% or 1/165 concentration).

## MANAGEMENT IMPLICATIONS

The use of capsaicin has potential for reducing wildlife damage and nuisance activities. Specifically, *Capsicum* oleoresins appeared to have a significant aversive effect on seed consumption by squirrels. Oleoresin-treated seeds of 100,000 SHU's and suet treatments of 24,000 SHU's nearly eliminated consumption by captive, food-deprived squirrels. However, even low concentrations (8,250 SHU's) of capsaicin-treated sunflower seeds and hearts will be largely avoided by free-ranging squirrels when a more palatable food item is available. The greatest success with deterring squirrels from capsaicin-treated birdseed will likely occur when more palatable foods (i.e., untreated seed, ear corn, acorns, or other mast) are available.

The tapioca-dextrin glue used to bind the pepper to the seeds is somewhat water-resistant; however, soaking the treated seed in a container of water will cause the glue to dissolve in about 5 minutes. Simply spraying water on treated seed, similar to a light rain, typically has no effect. It is recommended that birdseed be dispensed in a manner that protects the seed from rainfall, as wet seed may lose its appeal to birds and become moldy.

The added costs of treating birdseed with capsaicin (including labor, glue, and pepper), is about 90%. For example, incorporating a 20% concentration of hulled, pepper-coated sunflower seed into $2.00 worth of a commercial, packaged birdseed will increase the price to $3.80. Our experience from handing many nuisance-squirrel complaints indicates that many consumers would be willing to pay this added cost to reduce squirrel conflicts.

## LITERATURE CITED

Abacus Concepts. 1989. SuperANOVA. Version 1.11. Abacus Concepts, Inc., Berkeley. 320 pp.

Adler, W., Jr. 1988. Outwitting squirrels: 101 cunning stratagems to reduce dramatically the egregious misappropriation of seed from your birdfeeder by squirrels. Chicago Review Press, Chicago. 169 pp.

Andelt, W. F., K. P. Burnham, and D. L. Baker. 1994. Effectiveness of capsaicin and bitrex repellents for deterring browsing by captive mule deer. J. Wildl. Manage. 58:330–334.

Bevan, S., and J. Szolcsanyi. 1990. Sensory neuron-specific actions of capsaicin: mechanisms and applications. Tips 11:330–333.

Brugger, K. E. 1992. Repellency of sucrose to captive American robins. J. Wildl. Manage. 56:794–799.

Burton, R. 1992. North American birdfeeder handbook. Dorling Kindersley Ltd., London. 224 pp.

Chile Pepper Institute. 1994. Chile Institute Newsletter 4:6.

Dewitt, D., and N. Gerlach. 1990. The whole chili pepper book. Little, Brown and Co., Boston, MA. 373 pp.

Geisthovel, E., O. Ludwig, and E. Simon. 1986. Capsaicin fails to produce disturbances of autonomic heat and cold defense in avian species *(Anas platyrhynchos)*. Pfluegers Arch. 406:343–350.

Hoffman, P. G., M. C. Lego, and W. G. Galetto. 1983. Separation and quantitation of red pepper major heat principles by reverse-phase high-pressure liquid chromatography. J. Agric. Food Chem. 31:1326–1330.

Jakubas, W. J., P. S. Shah, J. R. Mason, and D. M. Norman. 1992. Avian repellency of coniferyl and cinnamyl derivatives. Ecol. Appl. 2:147–156.

Mason, J. R., N. J. Bean, P. S. Shah, and L. Clark. 1991. Taxonspecific differences in responsiveness to capsaicin and several analogs: correlates between chemical structure and behavioral aversiveness. J. Chem. Ecol. 17:2539–2551.

———, and J. A. Maruniak. 1983. Behavioral and physiological effects of capsaicin in red-winged blackbirds. Pharmacol. Biochem. Behav. 19:857–862.

Nagy, J. I. 1982. Capsaicin—a chemical probe for sensory neuron mechanisms. Pages 185–235 *in* L. Iversen, S. D. Iversen, and S. H. Snyder, eds. Handbook of psychopharmacology, 15. Plenum Publ., NY.

Nutrition Reviews. 1986. Metabolism and toxicity of capsaicin. pp. 20–22.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach. McGraw-Hill Book Company, NY. 633 pp.

Suzuki, J. I., F. Tausig, and R. E. Morse. 1957. A new method for the determination of the pungency in red pepper. Food Technol. 11:100.

Swihart, R. K., and M. R. Conover. 1991. Responses of woodchucks to potential garden crop repellents. J. Wildl. Manage. 55:177–181.

Szolcsanyi, J. 1976. On the specificity of pain producing and sensory neuron blocking effect of capsaicin. Pages 167–172 *in* J. Knoll and E. Vici, eds. Symp. on Analgesics. Akademiai Kiado, Budapest.

———, H. Sann, and F-K. Pierau. 1985. Capsaicin and chemonociception in the pigeon, chicken, and guinea pig. Pfluegers Arch. 403(Suppl):R60.

———, ———, and ———. 1986. Nociception in pigeons is not impaired by capsaicin. Pain 27:247-260.

Todd, P. H. 1958. Detection of foreign pungent compounds: oleoresin *Capsicum*, ground *Capsicum* and chili spices. Food Technol. 12:468.

———, M. G. Bensinger, and T. Biftu. 1977. Determination of pungency due to *Capsicum* by gas-liquid chromatography. J. Food Sci. 42:660.