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Capsaicin-treated seed as a squirrel deterrent at birdfeeders

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Capsaicin-treated seed as a squirrel deterrent at birdfeeders

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Abstract: Eastern gray squirrels *(Sciurus carolinensis)* are considered to be a pest by many bird-lovers because they take significant quantities of seed from birdfeeders. None of the available methods of protecting birdseed against squirrels is completely effective. We assessed the efficacy of treating birdseed with capsaicin oleoresin as a means of deterring squirrels. Consumption of treated and untreated whole, black-oil sunflower seed was compared by carrying out one-choice feeding trials at 3 sites near Ithaca, New York, from 11 May to 24 June 1999. The heat strength of the treated seed was 40,000 Scoville Heat Units (SHUs) (2,424 ppm) on the shell and 2,000 SHUs (121 ppm) on the heart. At each site, we provided 600 g of seed at a feeding station for one 3-hr session each day, and recorded the weight of seed consumed. Observations of feeding behavior by squirrels, birds and Eastern chipmunks *(Tamias striatus)* were recorded throughout the 3-hr session on 2 days per week at each site during most weeks. Untreated seed was provided in weeks 1,2, and 4; capsaicin-treated seed was offered in weeks 3, 5, and 6. We concluded that treatment with capsaicin significantly reduced both the amount of seed taken by squirrels and the total time squirrels spent feeding. The reduction in squirrel feeding time was primarily due to a decrease in the duration of feeding visits. Visitation rates by birds were unaffected by seed type at 2 sites, and increased with the treated seed at the third site. Seed type had no effect on the species composition of the birds visiting the feeder. The treated seed was not effective in deterring Eastern chipmunks from taking the seed.

Key words: birdseed, capsaicin, *Sciurus carolinensis*, squirrel, repellent

Over 82 million people in the United States currently feed birds near their homes (U.S. Fish & Wildlife Service 1993). In 1991, homeowners spent over $2 billion on birdseed, and $500 million on related equipment (U.S. Fish and Wildlife Service 1993). The Eastern gray squirrel *(Sciurus carolinensis)* is attracted to birdfeeders and will often consume significant quantities of seed. Consequently, many bird-lovers would like to prevent squirrels from eating seed and damaging feeders. Although there are several designs of 'squirrel-proof birdfeeders commercially available, these are largely ineffective (Fitzgerald et al. 1995). Many bird-lovers would find other more extreme methods, such as trapping or shooting to be unacceptable or illegal. In addition, lethal control would be unlikely to provide a long-term solution.

An alternative method of protecting birdseed involves the use of capsaicin. Capsaicin is the pungent component in *Capsicum* plants that is responsible for the sensations people associate with eating chili peppers. The heat strength of capsaicin is traditionally measured in Scoville Heat Units

(SHUs), this value being the number of dilutions required to minimize detection of the 'heat' sensation. SHU values can now be measured by gas chromatography (Hoffman et al. 1983). Habenero peppers range in heat strength from 100,000-500,000 SHUs (6,060 - 30,300 ppm), while jalapenos are in the 5,000 - 20,000 SHU range (303 - 1,212 ppm) (Norman et al. 1992, Chili Pepper Institute 1994)

In mammals, capsaicin physically binds to a pain receptor, triggering the same neurological pathway as other painful stimuli (Nagy 1982, Bevan and Szolcsányi 1990, Andelt et al. 1992, Norman et al. 1992, Liu and Simon 1994, Surh and Lee 1995). Capsaicin has many other effects in mammals, including disruption of the thermoregulatory system (Jansco-Gabor et al. 1970, Obal et al. 1981, Szolcsányi et al. 1986), and most mammals find capsaicin repellent (Rozin et al. 1979, Szolcsányi et al. 1986, Mason 1998, Wagner and Nolte 2000). Capsaicin has therefore been used to prevent damage by wild mammals in many situations for both homeowners and commercial producers (Swihart and Conover 1991, Andelt at al. 1994, Fitzgerald et al. 1995, Krahling et al. 1997).

Capsaicin affects birds differently than mammals. Mason and Clark (1995) found that European starlings *(Sturnus vulgaris)* are able to taste capsaicin, suggesting other bird species may also have this ability. Yet, certain bird species (for instance parrots) readily feed on the fruits of *Capsicum* plants (Norman et al. 1992). Also, several studies have shown that birds are unaffected by capsaicin. For instance, Norman et al. (1992) showed that capsaicin (16,500 SHUs) did not affect food consumption by cedar waxwings *(Bombycilla cedrorum)* or house finches *(Carpodacus mexicanus).* Szolcsányi et al. (1986) found that injections of O.lg/ml of capsaicin into the eyes and arteries of pigeons *(Colomba livia)* produced no protective reactions. Thermoregulation was unaffected by intravenous injections of capsaicin at low doses in domestic ducks (Geisthovel et al. 1986) and red-winged blackbirds *(Agelaius phoeniceus)* (Mason and Maruniak 1983). Also, capsaicin had no effect on oral or topical sensitivity in red-winged blackbirds (Mason and Maruniak 1983).

The reason for the difference in the action of capsaicin on birds and mammals is unclear (Geisthovel et al. 1986), but there is evidence to suggest that capsaicin receptors in birds do not trigger the pain pathway (Mason et al. 1991, Mason and Clark 1995). Because capsaicin repels mammals but not birds, it can be used to deter squirrels from eating birdseed. Fitzgerald et al. (1995) first explored this by conducting trials on captive and free-ranging squirrels. They observed a dose-dependent response rate (from 8,250 to 82,500 SHUs), and high capsaicin concentrations significantly reduced seed consumption by squirrels.

Later, Krahling et al. (1997) carried out a series of field trials on various birdseed mixes and heat strengths. They found that a seed mix that contained 8% sunflower seed treated with ground-pepper at a heat strength of 3,812 SHUs effectively deterred squirrels from consuming the seed. In addition, they found that the frequency of bird visits increased with capsaicin-treated seed.

These studies led to the development of SquirrelFree® birdseed mix (Snyder Seed Corporation, West Amherst, N.Y.) that was registered by the U.S. Environmental Protection Agency as a squirrel repellent (Environmental Protection Agency Reg. No. 68563-1). The composition and treatment of this seed mix is the same as that tested by Krahling's group mentioned above. However, some people prefer to provision birdfeeders with 100% whole sunflower seeds in order to attract certain bird species. Consquently, Snyder Seed Corporation sought to produce a capsaicin-treated, whole sunflower product. Because squirrels can learn to open capsaicin-treated sunflower shells to obtain the untreated heart (Fitzgerald et al. 1995), Snyder Seed developed a new process to treat sunflower seed, so that both the shell and heart were coated with capsaicin oleoresin (produced by distilling *Capsicum* powder in a solvent). We tested this formulation in one-choice feeding trials to assess its efficacy as a squirrel deterrent at birdfeeders, and to examine its effect on bird visitation rates.

Study areas

Initially, we checked 5 potential sites for squirrel activity near Cornell University, Ithaca, New York. At each site, we placed approximately 600 g (more than adequate for 1 day; Fitzgerald et al. 1995) of commercial birdseed (Favorite; Sunflower Inc., Grandin, N.D.) on a wooden feeding table. Each table measured 40.6 x 40.6 cm, and had 4, 15.2 cm high legs (Fitzgerald et al. 1995). The sites were visited every 2 - 3 days to replenish the seed and make casual observations. During January and February 1999, we selected the 3 sites with the highest squirrel activity for this study, as indicated by the amount of seed taken and number of squirrels observed. All study sites were predominantly forested with some human activity.

Tower Road

The Tower Road site was located on Cornell campus (42° 26' 54" N, 76° 28' 24" W) on a wooded slope. The dominant tree species here were white pine *{Pinus strobus),* balsam fir *{Abies frased),* dogwood *{Cornus florida)* and ashleaf maple *{Acer negundo).* The dominant ground cover was poison ivy *{Rhus radicans).* A seldom-used footpath ran within 4 m of the feeder, and the nearest road was approximately 50 m from the feeder.

Tennis Courts

The tennis courts were located in a small, wooded valley on the south side of Cornell campus, along Cascadilla Creek (42° 26' 33" N, 76° 28' 41" W). The only human activity in the immediate area was that of the tennis players. The major tree species included white pine *{Pinus strobus),* honey locust *{Gleditsia triacanthos),* black locust *{Robinia pseudocacia),* sugar maple *{Acer saccharinum),* black cherry *{Prunus serotina)* ash *{Fraxinus* sp.), Staghorn sumac *{Rhus typhina),* oaks *{Quercus* spp.), and buckthorn *{Rhamnus cathartica).*

Laboratory of Ornithology

A bird-feeding patio adjacent to the visitor center was used for observation at the Laboratory of Ornithology, 3 miles from Cornell University campus (42°28' 43"N, 76° 27' 5" W). The Laboratory is an 89-ha bird sanctuary comprised mainly of woodland, with some marshy patches. The major tree species here were white pine, white spruce *{Picea glauca),* red maple *{Acer rubrum),* river birch *{Betula nigra),* hornbeam *{Carpinus caroliniana),* red mulberry *{Morus rubra),* and serviceberry *{Amelenchier* sp.). The patio was contiguous with the woodland

and adjacent to a large pond, where many mallards *(Anas platyrhynchos)* and Canada geese *(Branta canadensis)* foraged during the study. Squirrels regularly fed at birdfeeders in the patio, so we removed these for the duration of the 3-hr feeding sessions. Apart from daily maintenance of the feeders, there was no human activity in the patio.

Methods

Feeding trials

One-choice feeding trials were conducted to determine the weight of seed taken and the behavior patterns of squirrels, chipmunks *(Tamias striatus),* and birds for both control and capsaicin-treated whole, black-oil sunflower seed. To produce the treated (Hot) sunflower seed, Snyder Seed Corporation developed a method by which the shell was cracked slightly, and the seed was soaked in a soy-oil carrier with capsaicin oleoresin providing a heat strength of approximately 40,000 SHUs (2,424 ppm) on the shell, and 2,000 SHUs (121 ppm) on the seed heart inside. Lipids such as soy-oil appear to enhance the heat strength of capsaicin (Fitzgerald et al. 1995). The control seed was untreated as our preliminary studies indicated that the soy-oil coating had no effect on seed consumption by squirrels.

Seed was offered daily for a 3-hr feeding session at each of the 3 sites according to the following sequence: 2 weeks of control seed, 1 week of Hot seed, 1 week of control seed, and 2 weeks of Hot seed (Table 1). This sequence allowed us to investigate the relationship between the amount of seed consumed, and the length of time it had been offered to squirrels, birds and chipmunks.

Feeding sessions commenced between 0800 and 0930 hrs. Using a Delta Range R balance (PM4600, Mettler-Toledo Inc., Columbus, O.H.), we weighed 600 g of seed, and placed it on a feeding table. The feeding table was placed on 2 adjacent plastic trays (62 x 36 cm) to catch spillage. Three hours later, all seed remaining on the table and trays was collected and weighed. If the seed had been dampened slightly by light rain during the 3-hr session, it was dried at 75°C for up to 4 hrs before being weighed. Seed was not provided when rainfall was heavy because squirrel activity was minimal.

Table 1. Treatment protocol for black-oil sunflower seed provided at 3 sites (Tower, Tennis and Lab) during each week of feeding trials with free-ranging gray squirrels, Ithaca, New York, 11 May - 24 June 1999.

Seed	**Week**	**Dates**
Control	1	11 -14 May
Control	2	17-24 May
Hot	3	31 May-7 June
Control	4	8- 11 June
Hot	5	14-18 June
Hot	6	21-24 June

Behavioral observations

Behavioral observations were made throughout the entire 3-hr feeding session on at least 2 days per week at each site during most weeks. Usually, observations were made on the first day that the seed type was changed, and again within the following 2 days. Observations were not made on days with heavy rain, or when temperatures exceeded 25°C, because squirrels were inactive. To minimize disturbance, squirrels were observed at a distance of at least 10 m from the feeding table. At the Lab, observations were made from inside the visitor center through an observation window.

We recorded each visit to the feeding table by squirrels, birds, and chipmunks. In the case of squirrels and chipmunks, visits were classed as feeding if the animal appeared to eat the seed, or, in the case of chipmunks put the seed in its cheek pouches; otherwise the visit was classified as non-feeding. For squirrels and chipmunks, the start and end time of each visit was recorded to the nearest second. For birds, we recorded the total number of visits made during the session by each species.

Data analysis

Data on weight of seed consumed and bird visits were available during all 6 weeks. However, in week 6, behavioral data for squirrels and chipmunks were excluded because of insufficient activity in the immediate vicinity of the feeding table. Data on the weight of seed consumed and duration of squirrel feeding visits were analyzed using Analysis of Variance (ANOVA) / General Linear Model (Minitab Statistical Software, Release version 12, Feb. 1998, State College, P.A.), and Tukeys pairwise comparison. For these analyses, data were grouped by week to investigate time effects. The first analysis used 'seed', 'site', 'week(seed)' and interactions of these variables as model terms. Because this showed a significant site effect, the same ANOVA was also carried out for each site, using 'seed' and 'week(seed)' and the interaction of these as model terms. Other averages were calculated from observation data for each week (e.g., mean number of squirrel visits per 3-hr session).

Results

Unless otherwise stated, the means presented refer to the average value per 3-hr feeding session for a specific week, and P-values are stated for significant differences.

Weight of seed consumed

The mean grams of seed consumed was higher for Control (215 g of 600 g [35%]) than for Hot (166 g) seed (pooling data from all sites) (P = 0.014). 'Site' also had a significant effect (P < 0.001), with the mean grams consumed (all sessions) at the Lab (312 g) being higher (P < 0.001) than that at Tower (172 g) and Tennis (99 g). Because of these site differences, sites were considered separately for further analyses.

Tower Road. The mean grams of Control seed taken increased slightly from weeks 1 (156 g) to 2 (244 g), then decreased by 87% (P = 0.013) to 32 g when Hot seed was offered in week 3 (Figure 1). When control seed was offered in week 4, mean intake increased (P = 0.027) to 238 g, returning to the week 2 level. Intake decreased again with Hot seed in week 5 (87 g) though this was higher than in week 3. Mean grams of Hot seed taken increased slightly (32%) from weeks 5 to 6 (115 g). Overall, the mean grams taken per 3-hr session was lower for Hot (75 g) than control (240 g) seed (69% reduction; P < 0.001)

Tennis. The mean grams of Control seed consumed was similar for weeks 1 and 2 (181 g and 152 g respectively; Figure 1). When Hot seed was supplied in week 3, mean intake was reduced by 82% (28 g; P < 0.001). Intake increased in week 4 (177 g)

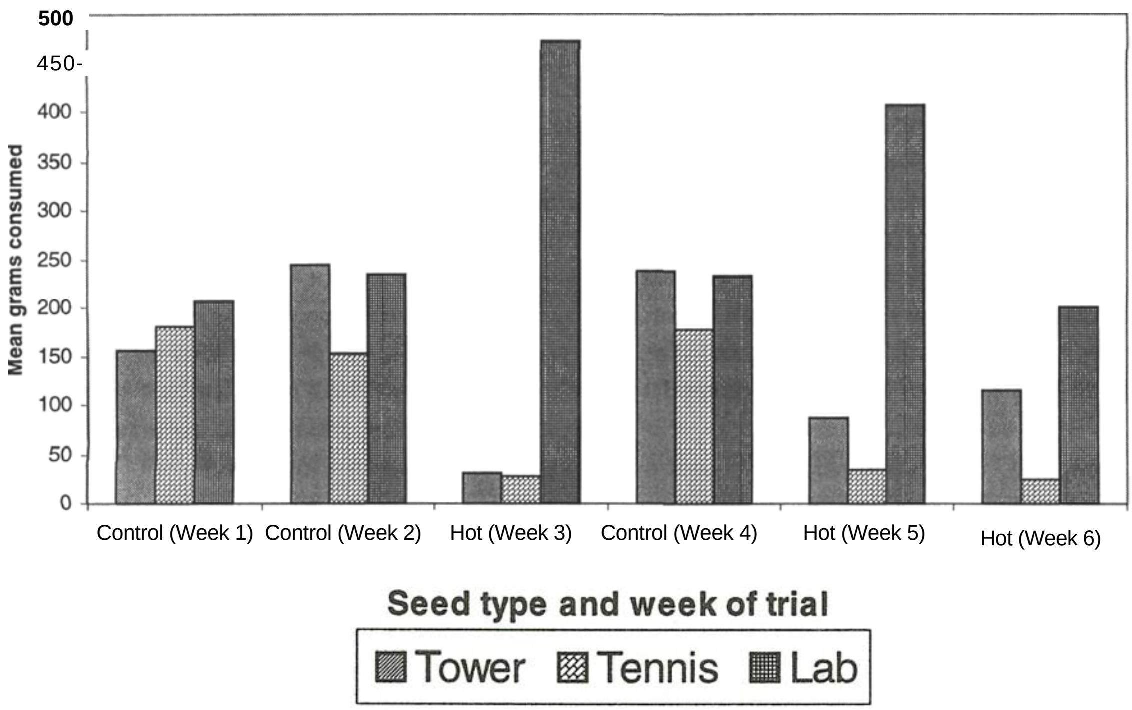

Figure 1. Mean grams of seed consumed per 3-hr feeding session for each week at 3 sites Tower, Tennis and Lab), Ithaca, New York, 11 May - 24 June 1999. Seed was untreated (Control) in weeks 1, 2 and 4, and capsaicin-treated (Hot) in weeks 3, 5 and 6.

when Control seed was offered again *(P* < 0.001), and was similar to levels for weeks 1 and 2. When Hot seed was given in week 5, intake again dropped (80% reduction, *P* < 0.001) to 35 g, which was similar to week 3. The mean grams taken in week 6 (25 g) was very slightly lower than that in week 5. Considering data from all sessions, mean intake was lower for Hot than for Control seed *(P* < 0.001; 34 g and 169 g respectively; 80% reduction).

Laboratory of Ornithology. The mean grams of seed consumed was very similar in weeks 1 (206 g) and 2 (235 g) when Control seed was provided (Figure 1). In week 3, when Hot seed was provided, intake increased dramatically to 472 g (100% increase; *P* = 0.029). When Control was offered again in week 4, there was a decrease to 232 g (similar to that in Control weeks 1 and 2), though this was not significantly lower than week 3. Intake increased again with Hot seed in week 5 (407 g; increase of 175%). Mean intake of Hot seed was thus similar in weeks 3 and 5, but it dropped to a higher *(P* = 0.011) for Hot (312 g) than for Control (255 g), representing a 22% increase. Overall, the mean grams taken per 3-hr session was higher for Hot (366g) than for Control (225g) seed *(P* < 0.001; 62% increase).

Squirrel behavior

General behavior. On some occasions when Hot seed was offered, squirrels came within 2 m of the table, but did not jump on to it; on others, they did jump on and walked around the table edge, sniffing and sometimes eating small amounts of the seed, then quickly leaving the table (see details of lengths of feeding and non-feeding visits below). Squirrels would often partially close their eyes while feeding on Hot seed, and would periodically wipe their mouths on the table. When a squirrel left the table, it would usually wipe its mouth on the ground or on a fallen branch, and would sometimes rub its ventral surface on the ground and roll over. Sometimes, squirrels would return again to the table and briefly feed again on the Hot seed.

Analysis of behavioral data. Considering data from all 3 sites, both seed-type ($P < 0.001$) and site ($P < 0.001$) had significant effects on squirrel visit duration. Further details from this analysis, together with a comparison of the sites are given at the end of this section. Because of the site effect on both visit duration and weight of seed consumed, the ANOVAs for each site are discussed here first.

One of the variables calculated was the 'mean total squirrel feeding time' (per 3-hr session) for a particular week. This was defined as the total time spent feeding by all squirrels during each observation session in a week, divided by the number of observation sessions in that week. Thus, because 2 or more squirrels were often feeding at once, the total (and mean) squirrel feeding time per 3-hr session could be greater than 3 hrs.

Tower. The mean number of feeding visits doubled from week 1 to 2 (11.0 to 21.5 visits), then decreased greatly when Hot seed was offered in week 3 (8.0 visits; Figure 2). The mean dropped even lower in week 4 (Control) to 3.0 visits. It increased again in week 5 (Hot) to 9.3, making the means for both Hot weeks similar.

Mean total squirrel feeding time increased from week 1 (154.0 mins) to week 2 (247.0 mins), then decreased by 78% in week 3 (54.7 mins), when Hot seed was offered (Figure 3). There was a slight increase to 86.0 mins in week 4 (Control), and then a slight decrease when Hot seed was given again in week 5 (63.2 mins). Thus, mean total squirrel feeding time was similar when Hot seed was offered in weeks 3 and 5. Considering all sessions for each seed-type, the mean total time was 177.6 mins for Control seed and 59.8 mins for Hot seed (a 66% reduction). Thus, mean total squirrel feed time was similar when Hot seed was offered in weeks 3 and 5. Considering all sessions for each seed-type, the mean total time was 177.6 mins for Control seed, and 59.8 mins for Hot seed (a 66% reduction).

Considering the duration of feeding visits, seed-type had a significant effect on duration ($P = 0.002$), with the means per 3 hrs. being 12.9 mins for all Control sessions and 6.8 mins for all Hot sessions. The mean duration of a single feeding visit was similar in week 1 (14.0 mins) and 2 (11.2 mins), then decreased in week 3 (6.8 mins) when Hot seed was offered (Figure 4). Mean duration increased to 28.7 mins with Control seed in week 4 ($P = 0.091$), then decreased markedly in week 5, when Hot seed was provided (6.8 mins).

Tennis. The mean number of feeding visits per session decreased from 28 in week 1 to 4.5 during week 2 (Figure 2). It increased in week 3 to 6 visits per session and stayed more or less the same in weeks 4 (7.0) and 5 (6.7).

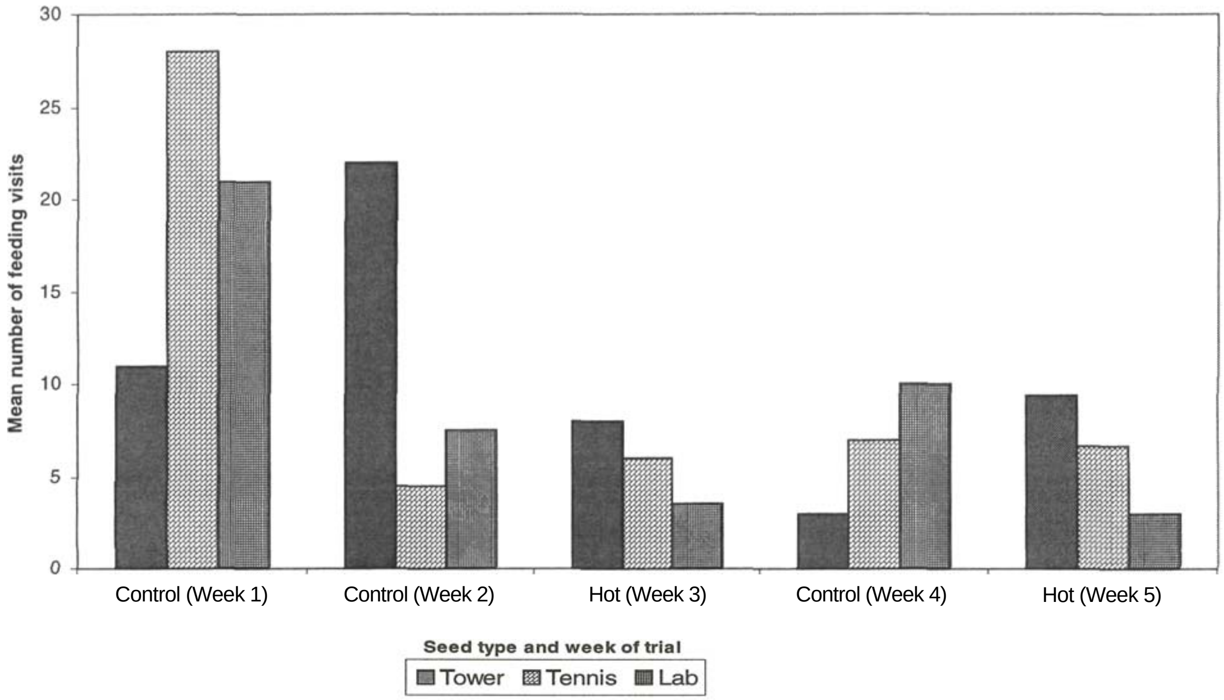

Figure 2. Mean number of feeding visits by free-ranging gray squirrels per 3-hr observation period during feeding trials for each week at 3 sites (Tower, Tennis, and Lab), Ithaca, New York, 11 May - June 1999.

Mean total squirrel feeding time per 3-hr session was highest during weeks 1, 2 and 4 (165.1, 61.2 and 77.7 mins respectively) when Control seed was offered (Figure 3).When Hot seed was given mean feeding time decreased to 11.2 mins in week 3 (82% reduction compared to week 2) and 39.7 mins in week 5 (49% lower than week 4). Considering all sessions, the mean total feeding time was 91.3 mins with Control seed and 28.3 mins (a 69% reduction) with Hot seed.

The duration of feeding visits was significantly affected by seed-type, with the mean duration being 8.3 mins for all Control sessions and 4.4 mins for all Hot sessions (*P* = 0.006). The mean duration increased from 5.9 to 13.6 mins from weeks 1 to 2, then dropped to 1.9 mins in week 3 (P = 0.023; 86% reduction) when Hot seed was given (Figure 4). During week 4 (Control), mean duration increased to 11.1 mins, then decreased again in week 5 to 6.0 (46% lower). Mean visit duration when Hot seed was offered was therefore lower in week 3 than in week 5.

Laboratory of Ornithology. The mean number of feeding visits per 3-hr session decreased from 21 in week 1 to 7.5 in week 2 (Figure 2). During week 3 (Hot), there was a further decrease to 3.5 visits per session. When Control seed was supplied again in

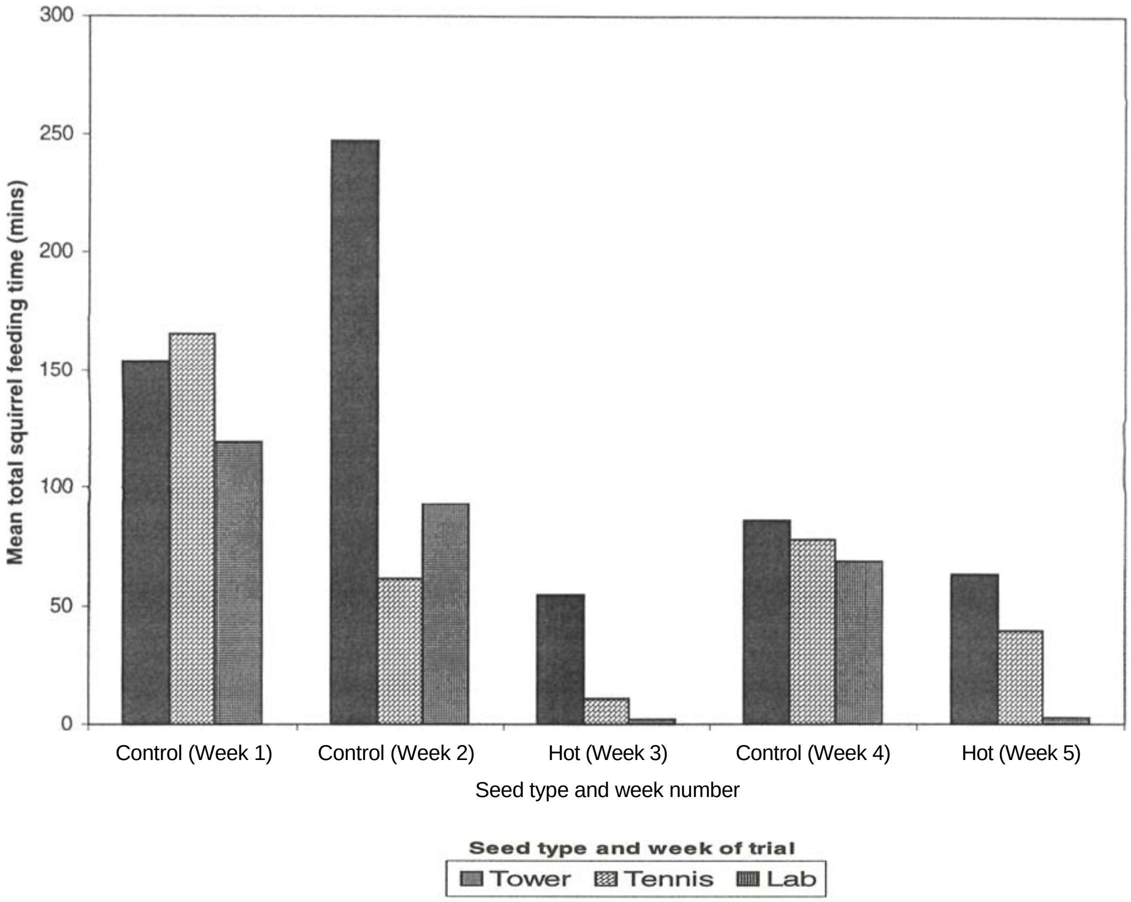

Figure 3. Mean total feeding time by free-ranging gray squirrels per 3-hr observation session during feeding trials, for each week at 3 sites (Tower, Tennis and Lab), Ithaca New York 11 May -24 June 1999.

week 4, the mean number of visits increased to 10. Visitation rates fell again to a mean of 3 visits per session with Hot seed in week 5.

Mean total feeding time per 3-hr session decreased slightly from weeks 1 to 2 (119.0 mins to 92.5 mins), then dropped dramatically to 2.0 mins (98% reduction) in week 3 when Hot seed was given (Figure 3). When Control seed was offered again in week 4, mean total feeding time increased again to 68.7 mins, then decreased greatly (96% reduction) once more in week 5 with Hot Seed (2.8 mins). Overall, there was a 97.5% reduction in total feeding time when Hot seed was given (2.4 mins), compared to that with Control seed.

Seed type had a significant effect on the duration of a single feeding visit *(P = 0.011)*, with mean duration for all sessions being 7.3 mins for Control and 0.56 mins for Hot (92% less). Mean duration increased from 5.9 mins in week 1 to 12.3 mins in week 2 (Figure 4). In week 3 (Hot), mean duration fell markedly (0.6 mins). When Control seed

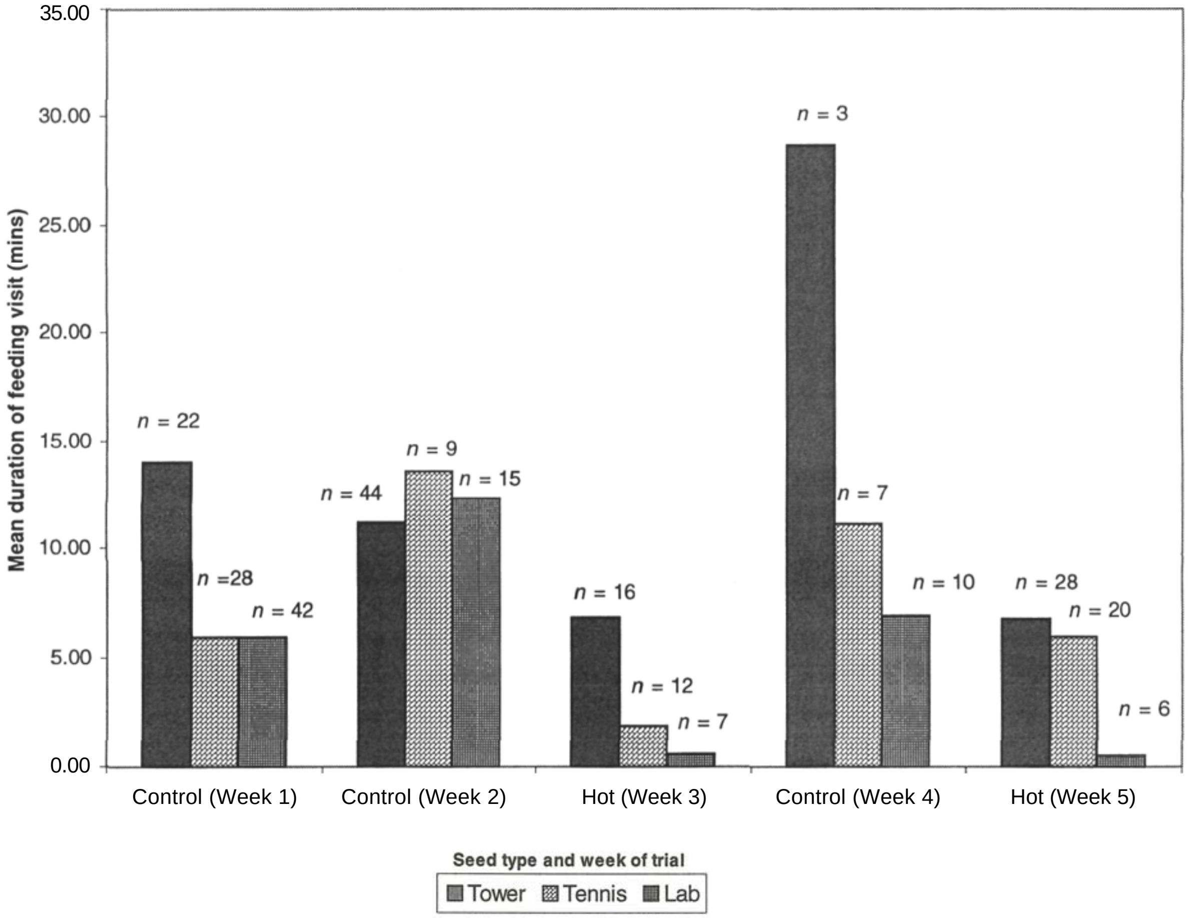

Figure 4. Mean duration of feeding visits by free-ranging gray squirrels in feeding trials, for each week at each site (Tower, Tennis and Lab), Ithaca, New York, 11 May - 24 June 1999. N = total number of squirrel feeding visits during the specified week.

was given again in week 4, the mean duration increased to 6.9, but fell again to 0.6 mins in week 5 with Hot seed.

Summary of feeding duration at all sites. Visit duration was lower in each of the Hot weeks 3 and 5 (mean = 3.9 and 5.8 mins respectively) than in Control weeks 2 and 4 (mean = 11.8 and 11.6 respectively) ($P < 0.009$ in all cases). Visits of less than 1 min duration accounted for 51% of the visits in week 3 and 35% of those in week 5.

Considering data from all sites, the duration of feeding visits was shorter when Hot seed was offered (mean = 5.0 mins, $n = 89$) than when Control seed was given (mean = 9.4 mins, $n = 180$, $P < 0.001$). The maximum durations for Hot and Control seed were 97.7 and 53.5 mins respectively.

Chipmunk behavior

Most visits were 1 min or less in duration when both Control and Hot seed was

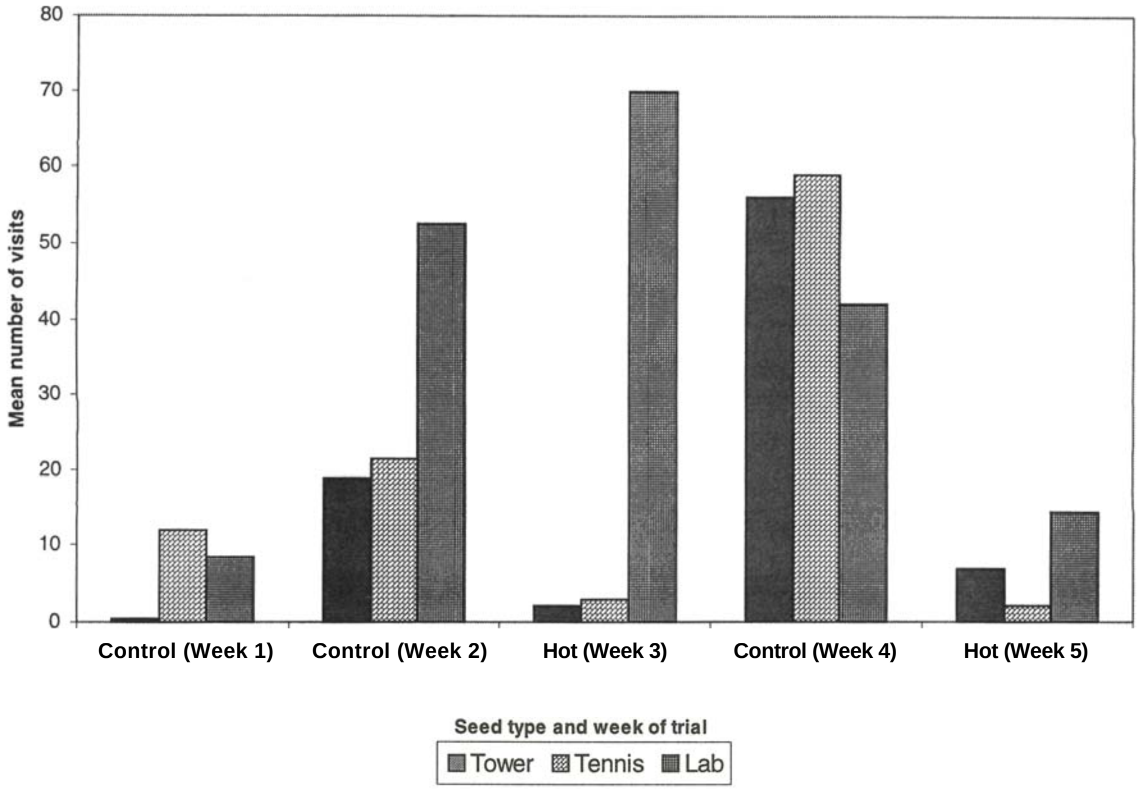

Figure 5. Mean number of visits to feeding station by free-ranging Eastern chipmunks per 3-hr observation session during feeding trials, for each week at 3 sites (Tower, Tennis and Lab), Ithaca, New York, 11 May - 24 June 1999.

offered (56.1 and 57.2% respectively). Chipmunks did not appear to eat the seed at the table. Instead they filled their cheek pouches with seed, then left the table (presumably to take the seed to a hoarding site), and returned to the table almost immediately. Individual chipmunks continued with this pattern for anything from a few minutes to approximately 1 hr.

At Tower during weeks 1 (Control), 3 and 5 (both Hot) there were very few chipmunk visits (Figure 5). The highest numbers of visits were during weeks 2 and 4 (mean = 19 and 56, respectively). Tennis showed a similar pattern to this, with the lowest frequency of chipmunk visits occurring in weeks 1, 3 and 5 and the highest in week 4. There were considerably more chipmunk visits at the Lab than at the other sites. The mean number was highest in week 3 (70), and lowest in week 1 (8.5). The frequency of visits was also high at the Lab in weeks 2 and 4 (means of 52.5 and 42 respectively).

Bird behavior

At Tower, the mean total number of bird visits per 3-hr observation session was similar in weeks 1, 3 and 4 (20 - 27 visits; Figure 6). The highest frequency of visits occurred when Hot seed was provided in

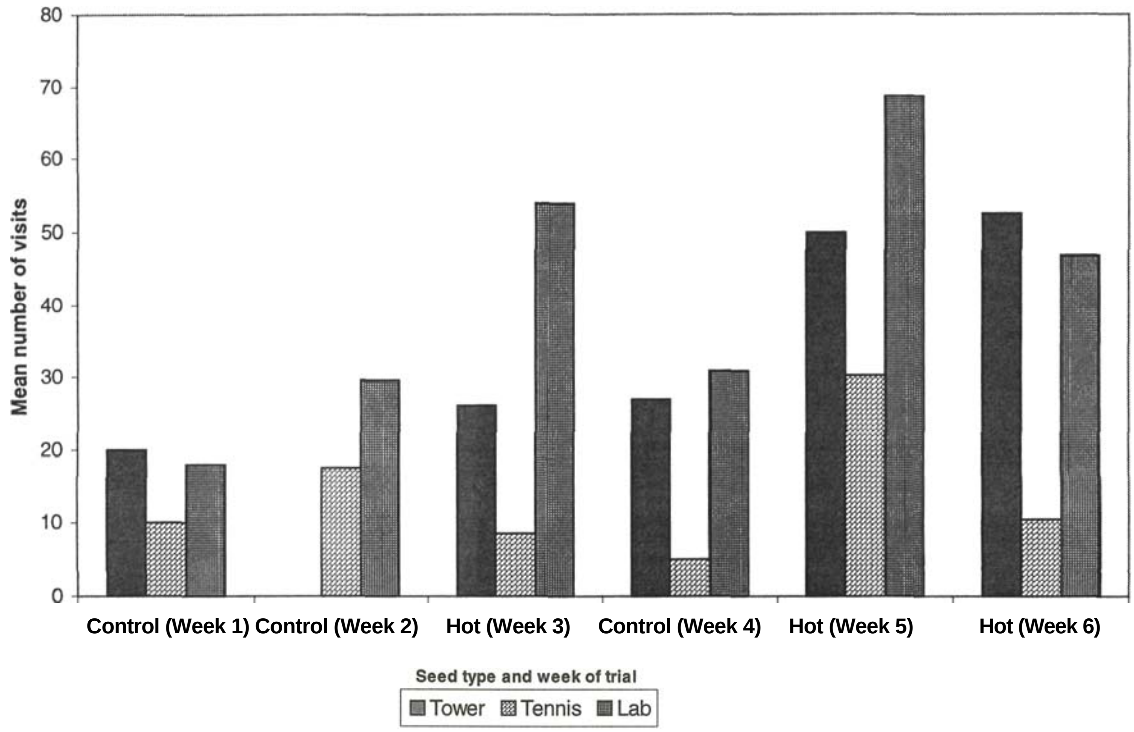

Figure 6. Mean number of visits by birds per 3-hr observation session during feeding trials, for each week at 3 sites (Tower, Tennis and Lab), Ithaca, New York 11 May - 24 June 1999.

week 5 (mean = 42.6). At Tennis, the mean number of bird visits was low (< 18) throughout the study. Visitation rates were higher at the Lab than at the other sites during most weeks. The mean number of visits was noticeably higher when Hot seed was offered (54, 61 and 58 in weeks 3, 5 and 6, respectively) than for Control sessions (18,30 and 31 in weeks 1, 2 and 3, respectively). Considering data from all sites, the mean number of visits (all species) per session was higher when Hot seed was offered (40 visits, n = 15) than for Control sessions (17 visits, n = 14).

The percentage of the total bird visits by each species was similar for both Control and Hot sessions (Table 2). The 2 most frequently recorded species were bluejays (45% of total) and chickadees (27%) at Tower; juncos (38%) and nuthatches (23%) at Tennis; and grackles (54%) and red-winged blackbirds (38%) at the Lab (Table 3).

Table 2. Number of visits *(n)* by each bird species as a percentage of total bird visits during feeding trials at all 3 sites (Tower, Tennis and Lab), Ithaca, New York, 11 May - 24 June 1999.

	Control		Hot	
Species	% total	*n*	% total	*n*
Bluejay *{Cyanocitta cristata)*	13.17	32	19.29	15
Cardinal *{Cardinalis cardinalis)*	10.29	25	9.64	76
Chickadee *{Parus atricapillus)*	11.93	29	12.82	10
Mallard (Anas platyrhynchos)	0.00	0	2.41	19
Grackle *{Quiscalus quiscula)*	24.69	60	24.24	19
Junco *{Junco hyemalis)*	10.70	26	8.38	66
Mourning dove *{Zenaida macroura)*	0.00	0	1.02	8
Nuthatch *{Sitta carolinensis)*	2.88	7	3.68	29
Red-winged blackbird *(Agelaius phoeniceus)*	25.10	61	15.10	11
Sparrow (song, chipping, house) *{Melospiza melodia, Spizella passerina, Passer domesticus)*	1.23	3	0.00	0
Titmouse *{Parus bicolor)*	0.00	0	3.43	27
Total	100	243	100	788

Table 3. Number of visits *(n)* by each bird species as a percentage of total bird visits during feeding trials at 3 sites (Tower, Tennis and Lab), Ithaca, New York, 11 May - 24 June 1999.

	Tower		Tennis		Lab	
Species	% total	*n*	% total	*n*	% total	*n*
Bluejay *{Cyanocitta cristata)*	46.30	175	3.19	*6*	0.65	3
Cardinal *{Cardinalis cardinalis)*	20.11	76	12.77	24	0.22	1
Chickadee *{Parus atricapillus)*	29.37	111	10.11	19	0	0
Mallard *{Anas platyrhynchos)*	0	0	0	0	4.09	19
Grackle *{Quiscalus quiscula)*	0	0	0	0	53.98	251
Junco *{Junco hyemalis)*	4.23	16	40.43	76	0	0
Mourning dove *{Zenaida macroura)*	0	0	0	0	1.72	8
Nuthatch *{Sitta carolinensis)*	0	0	19.15	36	0	0
Red-winged blackbird *{Agelaius phoeniceus)*	0	0	0	0	38.71	180
Sparrow (song, chipping, house) *{Melospiza melodia, Spizella passerina, Passer domesticus)*	0	0	0	0	0.65	3
Titmouse(ParMS *bicolor)*	0	0	14.36	27	0	0
All	100	378	100	188	100	465

Discussion

Consumption by squirrels was lower when capsaicin-treated sunflower seed was provided at both Tower and Tennis. Conversely, at the Lab, overall intake was higher with Hot seed than with Control seed. This site difference was due to higher feeding pressure from chipmunks and birds at the Lab.

At all sites, total squirrel feeding time per feeding session was lower during weeks when Hot seed was provided than during the Control weeks. The capsaicin-treated seed therefore clearly acted as a squirrel deterrent. The muzzle-wiping behavior we observed was also seen by Fitzgerald et al. (1995) and Krahling et al. (1997) in their capsaicin trials, and was presumably an attempt by the squirrels to remove the capsaicin and reduce irritation. The decrease in total feeding time was mainly due to shorter visit duration rather than fewer visits. A high percentage of visits were less than 1 min in duration when Hot seed was offered. Nevertheless, some squirrels were evidently more tolerant, as we recorded a few visits of more than 30 mins duration.

At the Lab, the mean number of feeding visits by squirrels per 3-hr session was also lower when treated seed was offered, but this was not consistently so at the other sites. This variation reflects variation amongst squirrels in their sensitivity to capsaicin. Some were deterred from even sampling the Hot seed, which would have reduced the number of feeding visits. Others sampled the seed, and made many short feeding visits, interspersed with brief 'recovery' periods. This behavior would result in an increased frequency of visits.

The means for both total feeding time and visit duration by squirrels were similar during weeks 3 and 5 when Hot seed was offered at Tower and the Lab. This suggests that the efficacy of capsaicin-treated seed would not decrease over a short period of time, but further studies would be needed to determine the effects of long-term feeding of this seed on squirrel feeding behavior. The number of feeding visits and the total feeding time by squirrels varied considerably between weeks 1 and 2, even though control seed was offered during both weeks. Feeding activity increased at Tower, but decreased at Tennis and the Lab between weeks 1 and 2. It is not clear why feeding activity varied between sites when untreated seed was offered.

Chipmunks rarely visited feeding stations at Tower and Tennis, except in Week 4. However at the Lab, the mean number of visits was high in weeks 2-4. Reduced interspecific competition with squirrels accounts for the high chipmunk visitation rate during Week 3 at the Lab, as total squirrel feeding time was extremely low that week. Hot seed was not an effective deterrent for chipmunks. Their fur-lined cheek pouches (Stokes and Stokes 1986) evidently protected them from the immediate effects of capsaicin. Also, chipmunks may have a higher threshold for capsaicin tolerance than squirrels, as mammal species differ in this respect (Wagner and Nolte 2000). Chipmunks can store up to 70 sunflower seeds in their pouches (Stokes and Stokes 1986) weighing approximately 4.5 g. Thus, when chipmunks were making 40-60 visits per 3-hr session, they removed the majority of the seed taken.

Birds were also undeterred from feeding at the table when Hot seed was offered. In fact, the overall number of bird visits was more than twice as high with treated than with untreated seed. Consequently birds, like chipmunks, tended to avoid the table when squirrels were present. The decrease in total squirrel feeding time when Hot seed was provided, gave birds increased foraging opportunities. This effect was most obvious at the Lab during weeks 5 and 6, when ducks fed at the table for several minutes. Ducks consumed large amounts of seed in a short time (relative to other bird species, squirrels and chipmunks), which would account for the high weight of Hot seed taken at the Lab during these 2 weeks. Seed-type (control or hot) had little effect on the species composition of birds at feeders. Instead, differences among sites in terms of number of visits by each species reflected habitat differences. At the Lab, near the pond and marsh, the majority of bird visits were by red-winged blackbirds, grackles, and waterfowl. At Tower, where there was a mixture of wooded and grassy areas, the most frequently recorded species were bluejays and cardinals. Juncos and nuthatches were the most frequent visitors at Tennis, which was predominantly woodland.

Our study confirms Fitzgerald et al.'s (1995) and Krahling et al.'s (1997) findings that treating birdseed with capsaicin reduces consumption by squirrels. As part of their study, Krahling's group tested a seed mix that was similar to SquirrelFree (8% whole sunflower seed, at a heat strength of 4,000 SHUs). In one-choice trials carried out during the summer, they found that seed consumption was 93% lower for treated seed than control. This is a slightly greater reduction than we saw at the Tower (69%) and Tennis (80%), where seed consumption was primarily dependent on squirrel feeding time. This difference can be explained by the fact that the 100% sunflower seed we tested was considerably more attractive to squirrels than the birdseed mix, and repellent treatments are less effective on more attractive food sources (Swihart and Conover 1991).

Although most evidence to date suggests that birds would be unharmed by eating capsaicin-treated seed, negative effects have been reported. Injections of capsaicin at doses higher than 0.1% w/v (equivalent to 16,500 SHUs) affect thermoregulation when given intravenously, and eye-blinking when applied as a topical solution (Mason and Maruniak 1983). Austic et al. (1997) found that chickens fed on a mash of 3,500 SHUs for 6 months showed depressed egg production and hatchability. Free-ranging birds that supplement their diet with capsaicin-treated seed would not be expected to exhibit these reactions. However, further studies of the long-term effects of birds ingesting hot seed are needed.

Squirrels appear similar to deer *(Odocoileus* spp.) in their sensitivity to capsaicin (Andelt et al. 1994). However, squirrels are probably more sensitive to capsaicin than mountain beavers *(Aplodontia rufa)*, or beavers *(Castor canadensis)*, which are undeterred by a heat strength of 25,575 SHUs (Wagner and Nolte 2000). In contrast, pocket gophers *(Thomomys mazama)*, and porcupines *(Erethizon dorsatum)* are deterred by lower heat strengths than squirrels (Wagner and Nolte 2000).

In conclusion, whole sunflower seed treated with capsaicin oleoresin at 40,000 SHUs effectively deterred squirrels. This technique provides one potential solution to the problem of squirrels consuming seed at birdfeeders. This may have future applications for black bears *(Ursus americanus)* and other mammals that could damage birdfeeders.

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