DERMAL CONTACT REPELLENTS FOR STARLINGS: FOOT EXPOSURE TO NATURAL PLANT PRODUCTS

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Abstract: Identification and formulation of contact repellents are needed to prevent nuisance birds from roosting on architectural structures. In this study I showed the feet of starlings (*Sturnus vulgaris*) to be viable routes of exposure for contact dermal irritants, and that starlings will avoid perches treated with such irritants. In one experiment, starlings became agitated and hyperactive after their feet were immersed in 5% oil extracts of the spices cumin, rosemary and thyme, demonstrating that dermal exposure to chemicals could alter behavior. In a second experiment, I painted perches with pure compounds of plant origin (1% wt/wt). Starlings avoided perches treated with either R-limonene, S-limonene, and β-pinene. The carbamate pesticide, methiocarb, was also a good dermal repellent. None of the extracts or compounds indicated that exposure resulted in illness for the dosages given and the delivery system tested. These results suggest that development of a nonlethal contact repellent for nuisance bird control may be feasible.

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Key words: activity patterns, avian repellent, bird control, contact repellent, dermal irritant, perch, pest control, repellent, roost, starling, *Sturnus vulgaris*, toxicology.

Preventing birds from resting on architectural structures is a significant component of pest control operations. Accumulation of bird feces may pose health risks to humans, lead to physical damage to the structure of buildings, or decrease a structure's aesthetic appeal. Methods of bird control range from employing hazing techniques (e.g., pyrotechnics, effigies), erecting physical barriers (e.g., Nixalite®, Nixalite of America, East Moline, Ill., netting), applying polybutene products to surfaces, trapping and relocation, and the use of poison bait programs (Hygnstrom et al. 1994). However, 2 concerns arise in employing the above techniques. Use of hazing devices, physical barriers, and polybutene products are of concern because they may detract from the aesthetic appeal of an architectural structure, or in some cases exacerbate damage to the structure. Lethal control may affect non-target species and may be publicly unacceptable. If the above control strategies are not employed, there are few remaining viable alternatives for the resolution of this conflict between wildlife and humans.

Nonlethal chemical repellents have been used in situations where the resource to be protected can be ingested by birds (Mason and Clark 1992). However, orally delivered repellents offer little help in keeping birds off structures. The resource to be protected on structures is substrate and space. Thus, to be effective, the repellent must be targeted towards the appropriate sensory organ, e.g., the skin on the foot. Such a repellent might cause dermal irritation that the bird may seek to avoid, or the food may act as a conduit for a toxicant that serves as the unconditional stimulus in the formation of a learned avoidance response. Besides a tactilely mediated avoidance, e.g., polybutenes, no contact repellent deliverable to the foot exits.

The negative consequences of dermal exposure of toxicants to animals is well-known, and minimizing exposure has been a goal of workers in toxicology, cosmetology, dermatology, industrial hygiene and environmental health (Serat et al. 1973). Yet the permeability of skin to chemicals has been exploited for positive benefits as well. Dermal delivery has been used to deliver drugs to animals (Kemppainen and Reifenrath 1990), and as a method for the lethal control of pest birds (Goodhue and Cantrel 1964, Moore 1964*a,b;* Reinert and Cantrel 1967, Kare 1972).

Percutaneous adsorption of chemicals varies as a function of the thickness of the skin. In birds, the thinnest skin layers are covered by feathers, while the thickest layers are in exposed featherless areas, e.g., coverings of the beak and feet (Stettenheim 1972). Despite the apparent thickness of the skin of a bird's foot, the skin can be thin at the hinges between the scales.

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Moreover, because of the constant mechanical action associated with perching, chemicals may have access to easily penetrable transmission routes (Srivastava and Parasare 1971, Rogers et al. 1974, Hudson et al. 1979). Thus, for birds, the absorption of irritants and toxicants through the feet represents a viable route for chemical delivery (Fowle 1972).

Because chemically receptive fibers are found in higher densities in tissue with higher absorptive potential, e.g., mucous membranes, thin skin (Green et al. 1990), I hypothesized that these areas also might be sensitive to the irritating qualities of chemicals and form the basis of a sensorially mediated repellency. Alternatively, if chemicals absorbed through the feet cause illness, it may be possible to train birds to avoid visual targets using classic conditioning paradigms (e.g., Mason and Reidinger 1983). In this study, I explored the possibility that dermal exposure to naturally derived compounds may serve as an effective method to prevent birds from perching on chemically treated surfaces. If successful, such methods have application as roost disruptors and protective agents for use on architectural structures.

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METHODS

Adult European starlings were decoy-trapped at Sandusky, Ohio, and transported to the laboratory in Philadelphia where they were kept in group housing until selected for experimentation. Starlings were maintained on chick starter mash ad libitum supplemented with a vitamin mixture and fresh apples (weekly) throughout the experiments. Tap water was available continuously. Starlings were maintained at a constant temperature (23 C), and 14:10 hours light:dark cycle during their residence in the laboratory.

Experiment 1

The object of this experiment was to determine whether caged starlings, whose feet had been immersed in oil extracts of spices, altered their activity patterns, food intake, or water consumption relative to controls.

I selected starlings from group-housing and housed them individually (cage dimensions: 120 × 60 × 60 cm) for a 7-day adaptation period during which I monitored their food and water intake, and perch-hopping behavior. All birds were isolated visually from one another. After adaptation, I randomly assigned birds to one of 2 experimental groups. As a prerequisite to proceeding to the next phase of testing, I verified similarity between the 2 groups for food and water intake and perch-hopping activity using separate repeated measures analysis of variance (ANOVA) analyses for each dependent variable. The repeated measures was day. Because a nonsignificant result was the criterion condition for continuing experiments, I did not summarize the results of the pretreatment analysis.

At the start of each of the 5 test-days, I provided starlings with clean perches. For the treatment group, I immersed the feet of the starlings in spice-extracted mineral oil for 60 seconds. For the control group, I immersed the feet of starlings in mineral oil for 60 seconds. I returned the birds to their cages, and after a 15-minute adaptation period, I monitored their perch-hopping activity, food intake, and water intake for a 2 hour period. (Clark and Mason 1993). At the end of the 5-day experiment I selected a new group of starlings for the next test spice and returned the original group of birds to the group-housing facility.

Each cage contained 2 perches positioned at opposite ends of the cage. Perches were held in place with U-shaped housing units containing tension springs. When depressed, e.g., when a bird rested on a perch, the dowel activated a contact switch and the event was scored on an electronic counter. I estimated an index of activity by summing the number of position transitions a bird made during a 2-hour period. I recorded transitions as a bird hopping from one perch to another, or from the floor of the cage onto a perch.

Test stimuli included: dried basil leaves, cumin powder, powdered ginger, dried rosemary leaves, sage powder, and dried thyme leaves. I prepared the test stimuli first, by grinding each to a fine powder in a mortar and pestle, then extracted the powder using an oil extraction technique, where 5 grams of spice was extracted with 100 mL of mineral oil at 25 C for 7 days. This method extracts lipid soluble essential oils, e.g, terpernoids (Gennaro 1990). Essential oils, at low concentrations, are often used as flavor additives (Furia and Belanca 1971, Taylor 1980), but at higher concentrations have irritating qualities (Budvarda 1983). After extraction, I decanted the supernatant and used the oil fraction as the test stimulus. I did not attempt to identify or quantify the concentration of extracted compounds in the supernatant.

I used a 2-way, fixed effects, repeated measures ANOVA to test for treatment and day effects for each of the 3 measures of behavior (i.e., perch-hopping, food intake, and water intake). I used a Scheffe test as the post-hoc evaluation for differences among means.

Experiment 2

The object of this experiment was to determine whether caged starlings exposed to perches treated with pure food-flavoring chemicals altered their activity patterns, food intake, or water consumption relative to controls. Avoidance of chemically treated perches in the absence of food or water intake suppression would be consistent with the interpretation of avoidance of contact dermal irritants. Decreased activity coupled with suppression of food or water intake would be consistent with illness induced inactivity.

I followed the same procedures outlined for Experiment 1 for subject selection, housing, adaptation, criterion for proceeding with testing, monitoring of perch-hopping, and food and water consumption.

I painted both perches in each cage with a starch paste containing 1% (wt/wt) test compound. The starch paste consisted of corn starch (CAS 9005-25-8) and water, mixed in a ratio of 1:10 (wt:wt). After drying, I introduced the perches into the cage and initiated recording 15 minutes after positioning of the treated perches. Control birds were exposed to perches treated with starch paste alone. I monitored activity, food consumption, and water intake for a 2-hour period. After the observation period, I replaced perches with clean wooden dowels. The next morning, I replaced the dowels with treated dowels and continued observations. I repeated this procedure for a total of 5 days. At the end of the experiment, I selected a new group of starlings for testing with the next compound and returned the previously used starlings to group housing.

I purchased reagent-grade test compounds commercially and these included: o-aminoacetophenone (Chem. Abstr. No. [CAS] 551-93-9: oAP), capsaicin (CAS 404-86-4: CAP), R-limonene (CAS 5989-27-5: RLIM), S-limonene (CAS 5989-54-8: SLIM), methiocarb (CAS 2032-65-7: METH), methyl anthranilate (CAS 134-20-3: MA), α-pinene (CAS 7785-70-8: APIN), β-pinene (CAS 19902-08-0: BPIN), D-pulegone (CAS 89-82-7: DPUL), zingerone (CAS : 1080-12-2: ZING). I selected compounds on the basis of their reported irritating potential to birds and mammals. Compounds reported to be general avian oral irritants, but not possessing general mammalian oral irritating properties were: oAP, MA, D-pulegone (Kare 1961, Clark and Shah 1991, Clark 1997). Compounds reported to be general mammalian oral irritants, but not general avian oral irritants were: CAP, RLIM, SLIM, APIN, BPIN, DPUL, ZING (Mason and Otis 1990). A compound with no-overall irritating quality, but having reported toxic qualities was METH (Dolbeer et al. 1994). Except for METH, all compounds selected are used as human food flavorings (Furia and Bellanca 1971).

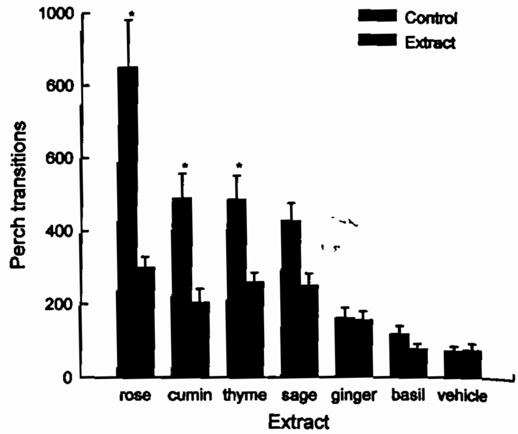

Fig. 1. Mean frequency of perch transitions for a 2-hour observation period as a function of spice extract. The feet of starlings were immersed in oil-extracted spice (solid bars) or the control vehicle, mineral oil (shaded bars) for 60 seconds. Bars depict 5-day averages of all individuals. Vertical capped bars depict 1 standard error.

RESULTS

Experiment 1

Exposing starlings to oil extracts of cumin, rosemary, or thyme resulted in significantly higher perch-hopping behavior relative to controls (Fig. 1, Table 1). In addition, there were temporal differences in perch-hopping activity for the treatment effect for rosemary and thyme (Table 1). Specifically, the starlings showed higher

Table 1. Summary of repeated measures analysis of variance for independent bioassays for perch-hopping activity for starlings whose feet were immersed in oil extracts of spices.

Extract	Treatment			Day			Treatment × day		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
Cumin	1, 10	11.47	0.006	4, 40	0.45	0.771	4, 40	0.75	0.564
Rosemary	1, 10	9.94	0.010	4, 40	2.87	0.035	4, 40	2.88	0.035
Thyme	1, 10	6.64	0.028	4, 40	9.03	0.001	4, 40	3.20	0.023
Basil	1, 8	0.55	0.479	4, 32	4.74	0.004	4, 32	0.09	0.986
Ginger	1, 10	0.01	0.938	4, 40	11.21	0.001	4, 40	0.767	0.553
Sage	1, 10	2.50	0.145	4, 40	3.96	0.008	4, 40	1.45	0.236
Vehicle	1, 8	0.01	0.941	4, 32	0.54	0.706	4, 32	1.45	0.241

levels of perch-hopping activity on days 1, 3, and 5 for rosemary, and increased perch-hopping activity on day 4 for thyme relative to controls. In contrast, the daily perch-hopping activity of starlings exposed to cumin extract was similar to controls (Table 1). The hyperactivity observed in starlings exposed to the cumin, rosemary, or thyme extracts did not affect other aspects of behavior. Starlings showed no signs of piloerection, nor did they differ from controls in food or water consumption (Table 2).

Exposing starlings to extracts derived from basil, ginger, sage, or the control vehicle, mineral oil, did not affect perch-hopping behavior (Fig. 1, Table 1). Nor did starlings exposed to any of the above treatments show evidence of piloerection or differences in consumption of food or water relative to the controls (Table 2).

Experiment 2

Starlings decreased their perch-hopping activity while in the presence of perches treated with R-limonene, S-limonene, methiocarb, or β-pinene relative to controls (Fig. 2, Table 3). The lower perch-hopping activity for birds exposed to these chemically treated perches appeared to be due to avoidance of the perches rather than apparent illness and general inactivity. I never observed starlings that were exposed to chemically treated perches to show signs of illness or piloerection. Moreover, during periodic inspection of birds through windows throughout the tests I observed starlings to exhibit normal activity, but this activity was biased toward the cage floor. Food and water consumption for birds exposed to chemically treated perches did not differ from control groups (Table 4).

Starlings increased their perch-hopping activity while in the presence of perches treated with o-aminoacetophenone (Fig. 2). Activity patterns differed across days between the control and treatment conditions (Table 2). Starlings may have become sensitized to the effects of oAP, because perch-hopping activity increased relative to controls on the fourth and fifth days of exposure. However, the hyperactivity did not co-occur with any differences between treatments for food or water consumption (Table 4),

Table 2. Summary of the mean intake across days for food (g) and water (mL) by starlings after immersion of starling's feet in an oil extraction of whole spice.

Compound	*n*	Food					Water				
		TRT[a]	SE[b]	CON[c]	SE	*P*[d]	TRT	SE	CON	SE	*P*
Basil	5	4.0	0.2	4.6	0.3	0.315	14.6	1.1	14.9	1.1	0.945
Cumin	6	4.2	0.2	4.7	0.1	0.172	12.2	0.9	13.2	0.5	0.524
Ginger	6	4.2	0.2	4.8	0.2	0.150	13.3	1.3	12.7	0.6	0.835
Rosemary	6	4.3	0.1	4.5	0.2	0.707	11.0	0.5	11.4	0.6	0.799
Sage	6	4.3	0.2	4.1	0.2	0.519	11.6	1.0	9.9	0.6	0.372
Thyme	6	5.0	0.2	4.9	0.2	0.964	13.0	0.8	12.8	0.7	0.898
Vehicle	5	3.7	0.2	4.1	0.2	0.248	15.3	1.2	15.4	0.4	0.949

[a] Treatment.
[b] Standard error.
[c] Control.
[d] *P* values reported are for the main treatment effect (oil extract of spice vs. oil vehicle) derived from the ANOVAs for each spice experiment. None of the interaction terms (day × treatment effect) had a $P < 0.150$. Because none of the interaction effects were significant at the $P < 0.05$ level, only the treatment effects are reported. The day effect was not considered to be of interest because it merely reflected experimental error rather than potential systematic sensitization or desensitization effects of the treatment relative to the control. The effect of the vehicle was determined by comparing intake patterns of birds whose feet were soaked in mineral oil to those birds whose feet were soaked in tap water.

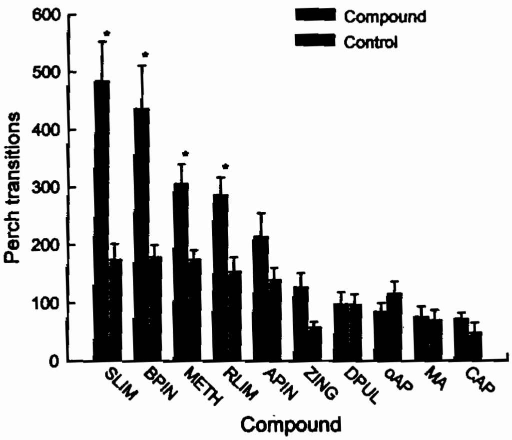

Fig. 2. Mean frequency of perch transitions for a 2-hour observation period as a function of flavor chemical. The perches were treated with a 1% composition of compound contained within a starch matrix. Solid bars depict the chemical treatment, shaded bars depict activity for the control condition, starch vehicle alone. Bars depict 5-day averages of all individuals. Vertical capped bars depict 1 standard error.

nor was there evidence of piloerection or illness for birds exposed to oAP-treated perches.

The presence of perches treated with capsaicin, methyl anthranilate, α-pinene, D-pulegone, or zingerone did not influence perch-hopping behavior of starlings relative to controls (Fig. 2, Table 3). Starlings exposed to perches treated with these chemicals did not show any signs of piloerection or illness, nor did they (with the exception of capsaicin) differ from controls in food or water consumption (Table 4). Although the pattern for food consumption varied across days for starlings exposed to capsaicin treated perches (Table 3), there was no clear pattern to suggest sensitization or desensitization, i.e., carry-over effects attributable to capsaicin.

DISCUSSION

In experiment 1, starlings were exposed to complex mixtures of compounds derived from spices, and the mode of delivery maximized the likelihood of dermal contact with extracted compounds. Furthermore, the perches available to the starlings were all untreated. Thus, this experiment was designed to assess the overall effect of exposure to compounds on activity rather than demonstrate a choice between treated surfaces. Starlings whose feet were immersed in oil extracts of cumin, rosemary, or thyme showed elevated perch-hopping activity relative to controls. Because there was no particular source of irritation, i.e., perches, the hyperactivity may be interpreted as a state of agitation associated with dermal exposure to extracted chemicals.

Spices are good sources of compounds that, in sufficient concentration, can act as dermal irritants (Budvarda 1983, Taylor 1980). However, the different efficacy among spices as agents causing behavioral change in bird activity merely may reflect different concentrations of essential oils available for extraction, or differences in composition for essential oils occurring in the spices. The significance of the experiment was not so much a positive identification of extracted compounds; rather, the significance of the experiment was the demonstration that exposure to extracted chemical through the feet could alter bird behavior.

Nonetheless, some interesting trends emerge from a qualitative comparison of essential oil content of the spices tested. Some of the major essential oil constituents held in common among cumin, rosemary, and thyme, but not major components of sage or basil are: p-cy-

Table 3. Summary of repeated measures analysis of variance for independent bioassays for perch-hopping activity for starlings exposed to perches treated with starch pastes containing reagent grade food flavorings.

Extract	Treatment			Day			Treatment × day		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
o-aminoacetophenone	1, 8	0.61	0.459	4, 38	4.25	0.007	4, 38	5.37	0.002
Capsaicin	1, 7	0.28	0.615	4, 28	0.85	0.506	4, 28	1.40	0.012
R-limonene	1, 10	7.94	0.018	4, 40	6.14	0.001	4, 40	1.15	0.217
S-limonene	1, 10	7.94	0.018	4, 40	6.14	0.001	4, 40	1.15	0.217
Methiocarb	1, 10	13.11	0.004	4, 40	6.77	0.001	4, 40	1.58	0.198
Methyl anthranilate	1, 8	0.01	0.928	4, 24	3.94	0.020	4, 24	0.24	0.865
α-pinene	1, 10	0.08	0.789	4, 40	1.76	0.157	4, 40	0.64	0.640
β-pinene	1, 10	7.03	0.024	4, 40	8.28	0.001	4, 40	2.79	0.039
D-pulegone	1, 8	0.00	0.980	4, 32	9.77	0.001	4, 32	0.71	0.590
Zingerone	1, 8	3.90	0.084	4, 32	7.12	0.001	4, 32	1.16	0.190

Table 4. Summary of the mean intake across days for food (g) and water (mL) by starlings after exposure to perches treated (TRT) with chemical or control (CON) vehicle.

		Food					Water				
Compound[a]	n	TRT	SE	CON	SE	P^b	TRT	SE	CON	SE	P^b
oAP	5	4.9	0.3	4.7	0.3	0.791	14.3	1.3	11.8	0.5	0.234
CAP	5	4.8	0.4	4.7	0.3	0.789[c]	13.5	0.5	13.0	1.2	0.794
RLIM	6	4.0	0.2	3.9	0.2	0.982	12.0	0.5	12.0	0.9	0.330
SLIM	6	4.9	0.4	4.9	0.2	0.302	13.0	0.8	12.0	0.8	0.657
METH	6	4.5	0.2	4.8	0.2	0.444	11.7	0.7	12.7	0.5	0.405
MA	5	4.8	0.5	4.1	0.4	0.535	13.4	0.8	12.1	0.9	0.723
APIN	5	5.0	0.5	4.8	0.4	0.789	12.8	0.5	14.6	1.1	0.449
BPIN	5	4.5	0.2	4.5	0.1	0.992	10.7	0.7	12.1	0.5	0.347
DPUL	5	4.6	0.2	4.8	0.4	0.432	14.2	0.9	13.5	0.6	0.145
ZING	5	5.0	0.2	4.8	0.3	0.833	14.6	0.5	15.4	1.1	0.692

[a] oAP (o-aminoacetophenone), CAP (capsaicin), RLIM (R-limonene), SLIM (S-limonene), METH (methiocarb), MA (methyl anthranilate), APIN (α-pinene), BPIN (β-pinene), DPUL (D-pulegone), ZING (zingerone).

[b] P values reported are for the main treatment effect (compound vs. control) derived from the ANOVAs for each compound. Unless noted otherwise, none of the interaction terms (day × treatment effect) had a $P < 0.150$. Because none of the interaction effects were significant, the day effect was not considered to be of interest; merely reflecting experimental error rather than potential sensitization or desensitization effects of the treatment relative to the control.

[c] There was a significant interaction for this analysis. See text for discussion of effects.

mene, α- and β-pinene, and limonene (Duke 1987). Experiment 2 showed that the limonenes and β-pinene act as contact repellents. Testing p-cymene may prove useful in the future. Other compounds contained in any of the spices also may have potential as contact repellents; their efficacy being a function of available concentration and transport properties.

In experiment 2, I showed that starlings decreased perch-hopping activity when exposed to perches painted with a starch matrix containing a 1% composition containing: R-limonene, S-limonene, methiocarb, or β-pinene. Although the time spent on perches was not quantified, direct observations indicated that starlings did not use perches treated with R-limonene, S-limonene, methiocarb, or β-pinene as resting perches. Birds in these treatment groups tended to spend more time on the cage floor relative to the other treatment groups and the controls. I interpret the decrease in perch-hopping activity as an avoidance of the treated perches.

The nonspecific hyperactivity observed in experiment 1, and the perch avoidance observed in experiment 2 are not inconsistent outcomes resulting from dermal exposure to chemicals. In experiment 1, the feet of birds were immersed in oil extracts. In this instance, birds would not be able to localize any presumed effect due to chemical irritation once placed in the test cage. A plausible consequence would be heightened agitation, resulting in the observed increase in perch-hopping activity. In experiment 2, the source of the chemical irritation was the perch. Because birds could locate the source of irritation within the test cage, it is reasonable to infer that the observed decrease in perch-hopping activity is consistent with perch avoidance. I do not believe that decreased activity was a result of illness brought on by dermal exposure to the chemicals tested. Percutaneous exposure of birds to toxicants in birds generally results in decreased activity, piloerection, and decreased food and water intake (Kare 1972, Rogers et al. 1974). However, because dermal exposure to the compounds did not appear to result in illness as evidenced by lack of piloerection, and there were similarities for food and water intake relative to the controls, it is arguable that the observed perch avoidance was due to avoidance of the contact irritants.

MANAGEMENT IMPLICATIONS

The concept of lethal bird control, whereby toxicants are delivered to birds through their feet, is well-established (Kare 1972). Also well-established is the notion that compounds can be potent dermal irritants. Reasoning that if bird feet are permeable to chemicals, they also might be sensitive to contact dermal irritants, some pest control operators attempted to expose birds to known mammalian irritants, i.e., capsaicin, in the hope that birds would avoid surfaces treated with such irritants. While the concept for this approach to nonlethal bird control may be valid, the choice of active ingredient was a poor one. All available behavioral and physiological evidence indicates that birds do not attend, or physiologically react to the potent mammalian irritant, capsaicin (Mason et al. 1991). Non-responsiveness to capsaicin was confirmed in this study.

I showed that agitation level of starlings can be increased by exposing their feet to compounds extracted from common spices. Agitation appears to occur when birds cannot locate the source of irritation. When birds can locate the source of dermal irritation, e.g., perches, they will avoid the source. The available evidence suggests that there is no short-term effect of exposure to these compounds on the well-being of the starlings, and no birds died as a result of exposure to these chemicals (they were held in captivity an additional 6 months beyond the termination date of the experiments). Together these laboratory results suggest that the approach of presenting avian irritants to the feet of birds for the purpose of dissuading them from resting on treated surfaces is feasible. Field testing of the approach remains to be done to test the efficacy of the bird management strategy.

LITERATURE CITED

BUDVARDA, S. 1983. The Merck Index. Tenth ed. Merck and Co, Inc., Rahway, N.J. 1463pp.

CLARK, L. 1997. A review of the bird repellent effects of 117 carbocyclic compounds. *in* J. R. Mason, ed. Repellents in wildlife management, Colorado State Univ. Press, Fort Collins. In Press.

———, AND J. R. MASON. 1993. Interaction between sensory and postingestional repellents in starlings: methyl anthranilate and sucrose. Ecol. Appl. 3: 262–270.

———, AND P. SHAH. 1991. Nonlethal bird repellents: in search of a general model relating repellency and chemical structure. J. Wildl. Manage. 55:538–545.

DOLBEER, R. A., M. L. AVERY, AND M. E. TOBIN. 1994. Assessment of field hazards to birds from methiocarb applications to fruit crops. Pest. Sci. 40:147–161.

DUKE, J. A. 1987. Handbook of medicinal herbs. CRC Press, Boca Raton, Fla. 677pp.

FOWLE, C. D. 1972. Effects of phosphamidon on forest birds in New Brunswick. Can. Wildl. Serv. Rep. Ser. 16:1–23.

FURIA, V., AND N. BELLANCA. 1971. Fenaroli's handbook of flavor ingredients. CRC Press, Boca Raton, Fla. 677pp.

GENNARO, A. R. 1990. Remington's pharmaceutical sciences. Mack Publ. Co., Easton, Pa. 2000pp.

GOODHUE, L. D., AND K. E. CANTREL. 1964. Method of repelling birds with substituted pyrimidine compounds. U.S. Patent 3,156,613. U.S. Patent Off., Washington, D.C.

GREEN, B. G., J. R. MASON, AND M. R. KARE. 1990. Chemical senses, irritation. II. Marcel Dekker, New York, N.Y. 361pp.

HUDSON, R. H., M. A. HAEGELL, AND R. K. TUCKER. 1979. Acute oral and percutaneous toxicity of pesticides to mallards: correlations with mammalian toxicity data. Toxicol. Appl. Pharmacol. 47: 451–460.

HYNGSTROM, S. E., R. M. TIMM, AND G. E. LARSON. 1994. Prevention and control of wildlife damage. Univ. Nebraska, Lincoln, Ne. 820pp.

KARE, M. R. 1961. Bird repellent. U.S. Patent 2,967,128. U.S. Patent Off., Washington, D.C.

———. 1972. Methods of bird control. U.S. Patent 3,663,692. U.S. Patent Off., Washington, D.C.

KEMPPAINEN, B. W., AND W. G. REIFENRATH. 1990. Methods for skin absorption. CRC Press, Boca Raton, Fla. 219pp.

MASON, J. R., AND L. CLARK. 1992. Nonlethal repellents: the development of cost-effective, practical solutions to agricultural and industrial problems. Proc. Vertebr. Pest Conf. 15:115–129.

———, AND D. L. OTIS. 1990. Effectiveness of six potential irritants on consumption by red-winged blackbirds (*Agelaius phoenicieus*) and starlings (*Sturnus vulgaris*). Pages 309–322 *in* B. G. Green, J. R. Mason, and M. R. Kare, eds. Chemical senses, irritation. II. Marcel Dekker, New York, N.Y.

———, AND R. F. REIDINGER. 1983. Importance of color for methiocarb-induced food aversions in red-winged blackbirds. J. Wildl. Manage. 47:383–393.

———, N. J. BEAN, P. S. SHAH, AND L. CLARK. 1991. Taxon-specific differences in responsiveness to capsaicin and several analogues: correlates between chemical structure and behavioral aversiveness. J. Chem. Ecol. 17:2539–2551.

MOORE, W. A. 1964*a*. Poison dispensing bird perch. U.S. Patent 3,147,565. U.S. Patent Off., Washington, D.C.

———. 1964*b*. Device for applying a liquid to the feet of roosting birds. U.S. Patent 3,146,546. U.S. Patent Off., Washington, D.C.

REINERT, J., AND K. E. CANTREL. 1967. Contact avicides. U.S. Patent 3,340,142. U.S. Patent Off., Washington, D.C.

ROGERS, J. G., JR., R. H. CAGAN, AND M. R. KARE. 1974. Percutaneous absorption of several chemicals, some pesticides included, in the red-winged blackbird. Environ. Physiol. Biochem. 4:104–111.

SERAT, W. F., R. J. FELDMAN, AND H. I. MAIBACH. 1973. Percutaneous absorption of toxicants. Pesticides. Natl. Pest Control Operator's News 33: 6–17.

SRIVASTAVA, D. N., AND G. C. PARASAR. 1971. Studies on toxic effects of malathion in fowls. Indian J. Anim. Sci. 41:1154–1158.

STETTENHEIM, P. 1972. The integument of birds. Pages 1–63 *in* D. S. Farner and J. R. King, eds. Avian biology. II. Acad. Press, New York, N.Y.

TAYLOR, R. J. 1980. Food additives. John Wiley and Sons, Chichester, N.Y. 126pp.

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