Human–Wildlife Interactions 14(3):409–418, Winter 2020 • digitalcommons.usu.edu/hwi

Repellent surface applications for pest birds

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Abstract: Common pest birds in the United States include the non-native European starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), and the pigeon (*Columba livia domestica*), as well as native birds including Canada geese (*Branta canadensis*) and gull species (Laridae). Large concentrations of pest birds can create human health hazards and monetary losses due to consumption of crops, depredation, and fecal contamination and accumulation. Fecal contamination hazards include the potential spread of zoonotic diseases including antimicrobial-resistant zoonoses and human injury due to the accumulation of fecal material on walking surfaces. Additionally, fecal accumulation causes structural and aesthetic damage due to the accelerated deterioration of building materials and increased maintenance costs. Methods to alleviate hazards and damages from aggregations of pest birds are needed. In a series of 3 experiments conducted in Fort Collins, Colorado, USA, between 2016 and 2018, we evaluated 3 surface-application repellent formulations for the reduction of fecal accumulations due to European starlings: Airepel® HC with castor oil, an anthraquinone-based repellent; Airepel HC with castor oil without anthraquinone; and MS2, a novel inert formulation with a tacky, oily texture. We compared each formulation directly to an untreated control. All 3 formulations reduced fecal accumulations beneath treated aluminum perches as compared to fecal accumulations beneath untreated aluminum perches. Interestingly, both formulations that contained no anthraquinone worked equally well or better than Airepel HC with castor oil, the anthraquinone-based formulation. The benefits of an exclusively inert formulation include less risk to applicators and non-target species. Comprehensive experimental field testing of these surface-application repellent formulations is warranted.

Key words: anthraquinone, European starling, fecal accumulation, hazards, inert, perch, pest birds, repellents, *Sturnus vulgaris*

The European starling (*Sturnus vulgaris*) is a widespread bird species with an estimated global population of 310 million (BirdLife International 2016) and 140 million individuals in North America (Jernelöv 2017). Starling roosts in the United States can vary in size from 2,000 up to 100,000 birds (Caccamise and Morrison 1988), with some large winter roosts containing 400,000–600,000 birds (LeJeune et al. 2008). Mixed flocks of starlings and blackbird (Icteridae) species have been reported to include up to 1.5 million birds (Glahn et al. 1991). Starlings are known to forage at livestock facilities throughout the United States (White et al. 1985, Glahn et al. 1989) and also use crop storage and processing facilities as roost sites (Clark 2014). Urban roosts are also common with starlings utilizing bridge supports, power lines, and buildings as roost locations (Thompson and Coutlee 1963).

One problem associated with large numbers of roosting birds is the accumulation of fecal material. A single European starling can produce 7.0–31.0 grams of feces a day, depending on diet quality (Geluso and Hayes 1999). Bird feces may be associated with several problems, including damage, safety, and health risks. Examples include hazards to humans due to the accumulation of fecal material on walking surfaces, structural and aesthetic damage due to the accelerated deterioration of building materials, and increased maintenance costs (Haag-Wackernagel 1995, Pimentel et al. 2000, Gingrich and Osterberg 2003, Giunchi et al. 2012).

Additional concerns related to the accumulation of large amounts of starling feces include hazards to human health due to the spread of pathogens with zoonotic disease potential. Studies have shown that starling fecal matter contaminates livestock feed with zoonotic pathogens, including *Escherichia coli* O157:H7 (LeJeune et al. 2008), *Salmonella* spp. (Carlson et al. 2011), and *Campylobacter* spp. (Sanad et al. 2013). European starlings have also been implicated in the spread of antimicrobial-resistant organisms among livestock facilities, including *E. coli* with reduced susceptibility to cefotaxime and ciprofloxacin (Medhanie et al. 2017) and *Salmonella* with antimicrobial resistance (Gaukler et al. 2009).

Methods are needed to alleviate bird problems related to fecal accumulation. A potential reason for unsuccessful attempts to disrupt bird roosts is a failure to address the cause of the birds' presence (e.g., foraging, roosting/loafing, and breeding). Behavior-based management involves manipulating the behavior of a species based on that species' biology (Fernández-Juricic 2016). If the ultimate goal is to reduce birds perching or roosting on structures, it follows that the application of a repellent to the area or surface would be needed to modify this behavior. Area repellents include physical (e.g., netting, owl models), audible (e.g., propane cannons, bioacoustics), and chemical repellents (see Mason and Clark 1995*a*) for a thorough review of avian repellents). Chemical repellents include surface contact repellents. Surface contact repellents generally have 2 modes of action: (1) tactile contact (where the tactile properties of the repellent are perceived as painful or uncomfortable), and (2) percutaneously absorbed (chemicals contained within the repellent are absorbed and cause physiological distress).

A review of bird repellents as surface applications (Seamans et al. 2013) revealed that glue (Reidinger and Libay 1979), tar (Belant et al. 1998), R-limonene, S-limonene, or β-pinene, and oil extracts of cumin, rosemary, and thyme (Clark 1997) deterred perching or elicited an agitation response. Glue-type repellents also called "entanglements" pose some problems, including trapping non-target species and unreliability in humid or dusty climates (Reidinger and Libay 1979, Fitzwater 1982). The majority of registered tactile repellents for birds contain compounds that are sticky or oily (e.g., aliphatic petroleum hydrocarbons, polybutenes, and polyisobutenes), thus causing birds to avoid these materials based on their textural and tactile properties (Clark 1998). Birds, like other animals, perceive their environment through multiple stimuli, including touch (i.e., skin contact; Seamans et al. 2013). Non-dietary routes of pesticide exposure have shown that birds are susceptible to chemical delivery through the pads of the foot (Mineau 2011). The skin on a bird's foot is thick except at the hinges between the scales, where the thickness varies (Lucas and Stettenhiem 1972). Thus, birds are susceptible to the absorption of repellents (e.g., irritants and toxicants) through their feet, and absorption is a viable route for chemical delivery (Clark 1997).

Airepel® HC (Arkion Life Sciences, New Castle, Delaware, USA) is an anthraquinone-based product currently marketed to solve bird problems on roofs, ledges, and other roosting areas. The mode of action of anthraquinone is not completely understood, although it is believed to cause negative post-ingestive consequences when used as a feed repellent (Werner and Provenza 2011). In earlier testing conducted with an anthraquinone-based repellent formulation, fish crows (*Corvus ossigragus*), brown-headed cowbirds (*Molothrus ater*), and red-winged blackbirds (*Agelaius phoeniceus*) occupied anthraquinone-treated aluminum perches less than untreated aluminum perches (Ballinger 2001). We evaluated 3 formulations of surface contact repellents with European starlings in a series of experiments.

Study area

Between 2016 and 2018, we conducted experiments at the National Wildlife Research Center's Outdoor Animal Research Facility in Fort Collins, Colorado, USA using 3–4 group cages (3 x 6 x 3 m) located within an open-sided building. We conducted experiments with captive European starlings (N = 440) captured in northern Colorado from 2016–2018. A maintenance diet (Purina Layena® pellets) and water were provided daily to all starlings during quarantine, holding, and testing. Digital video cameras (HDR-CX305E Sony® USA) were used on day 3 and days 4–6 to record bird interactions with treatments. It was not possible to record all cages throughout each experiment, and video failures due to lighting and memory card malfunction precluded the analysis of video data. A Colorado state scientific collection license authorized European starling captures, but because European starlings are not protected by the Migratory Bird Treaty Act of 1918 (16 U.S.C. 703-712), no federal scientific collecting permit was required. All experiments were performed in accordance with the ethical standards, relevant guidelines, and regulations per study protocol number QA-2593 approved March 2016 by the National Wildlife Research Center's Institutional Animal Care and Use Committee.

Methods

Experimental design

Most perch deterrent studies have used occupancy as a determination of effectiveness, evaluating time spent on a treated perch as compared to time spent on an untreated perch or perches (Scott and Schafer 1988, Stock and Haag-Wackernagel 2014). In contrast, goose (*Branta canadensis*) repellent studies have utilized fecal counts or dried mass of feces in treated versus untreated plots (Cummings et al. 1995, Mason and Clark 1995*b*, Devers et al. 1998). Fecal mass can be used to measure repellent efficacy in the context of human health hazards. Thus, we measured fecal accumulation beneath repellent-treated and untreated perches to evaluate the efficacy of surface-application repellents for group-housed European starlings.

This experimental design had 2 steps. First, because cage positional biases are well known (Jackson et al. 1998, Werner et al. 2010), we determined positional bias for perching during experiment days 1–3 ($D_{1\text{-}3}$). Second, we determined the ability of a treatment application of the repellent to neutralize or reverse the cage position bias for perching during the treatment period days 4–6 ($D_{4\text{-}6}$). These directional changes in position bias were taken as evidence of repellency.

To ensure that the amount of the treatment applied to each perch was similar among cages and experiments, we measured the weight of each untreated perch before applying each treatment. Following treatment application, we took a second weight, and the difference in these weights was recorded as the amount of treatment applied to each treated perch. For perches treated with Airepel HC with castor oil, we calculated the milligrams of anthraquinone per square meter of perch using the weight of the applied formulation multiplied by 33.3%. Airepel HC is 66.7% of the surface-application formulation, and Airepel HC is 50% anthraquinone; therefore, the surface application is 33.3% anthraquinone. Milligrams of anthraquinone per square meter was then calculated by dividing the milligrams of anthraquinone applied by the surface area of the perch in square meters. For perches treated with Airepel HC without anthraquinone, we calculated the milligrams of bentonite per square meter using the weight of the formulation applied multiplied by 13.3% because bentonite clay made up 13.3% of the surface application formulation. Milligrams of bentonite clay per square meter was then calculated by dividing the milligrams of bentonite applied by the surface area of the perch in square meters.

Repellent formulations

Airepel HC is an anthraquinone-based repellent formulation. Anthraquinone (CAS number 84-65-1; EPA registration number 69969-1) is a well-known and evaluated avian-feeding repellent (see DeLiberto and Werner 2016 for a review of testing and uses). For these experiments, we evaluated Airepel HC with castor oil as the first test formulation. Our second surface contact repellent was Airepel HC with no anthraquinone. Airepel HC with no anthraquinone is an experimental formulation that utilizes the inert ingredients of Airepel HC (as well as the added castor oil) and replaces the anthraquinone portion with bentonite clay (CAS number 1302-78-9). Bentonite clay is an absorbent aluminum phyllosilicate clay consisting mostly of montmorillonite. Our third surface contact repellent was MS2, which is a novel formulation of inert ingredients used for these experiments.

Experiment 1: Evaluation of Airepel HC with castor oil as a perch repellent

For step 1, we established 3 cohorts consisting of 45–48 starlings per cage (Figure 1). On the first day of the experiment, the floor of each cage was hosed to remove all fecal material. We installed 1 untreated aluminum perch on

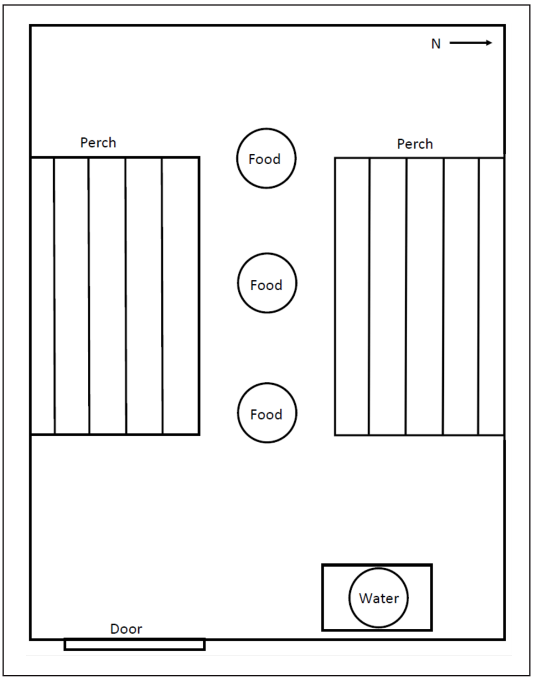

Figure 1. Diagram of 1 experimental cage used for European starling (*Sturnus vulgaris*) testing, 2016–2018, at the National Wildlife Research Center's Outdoor Animal Research Facility, Fort Collins, Colorado, USA. This figure shows a top-down view of a cage and the location of food and water bowls in relation to 2 aluminum perches (1.5 x 1.3 m) and 1 human access door.

the north and south sides of each cage. Each aluminum perch consisted of 5 1.5-m horizontal aluminum rods mounted on an aluminum frame. Extreme dimensions of the perch were 1.5 x 1.3 m. We collected feces each day (D_{1-3}) for each perch position and cage and placed these samples into a drying oven for 24 hours and recorded the stable dry weight (g). We used the larger average fecal weight of the positions (north or south) within each cage to determine the preferred perch location. Conversely, the perch in the position (north or south) associated with smaller average fecal weight was regarded as the non-preferred perch. A comparison of preferred versus non-preferred perches was made using a Wilcoxon matched-pairs test.

For step 2, we assigned the preferred perch locations within cohorts to receive the Airepel HC with castor oil application coating. The non-preferred perch served as the null application. On day 4, we replaced the non-treated perch at the preferred position with a perch coated with Airepel HC with castor oil. We applied Airepel HC with castor oil to these perches with a CO_2 backpack sprayer. The non-preferred perch remained as the untreated reference perch (null). The procedures for monitoring fecal deposition under perches during step 2 (D_{4-6}) followed those described in step 1. We averaged the dry fecal weight from each of the cages for D_{1-3} and D_{4-6} (3-day averages). We defined the change in behavior (perch preference) as $\% \Delta = \{[(D_{4-6}) - (D_{1-3})]/ (D_{1-3})\}e$ where *e* was the experimental manipulation: coating with Airepel HC with castor oil or not coated (null). This metric allowed for an easy visual comparison of the magnitude of the experimental effect across cages and times for all experiments. A comparison of preferred versus non-preferred perches was made using a Wilcoxon matched-pairs test.

Experiment 2: Comparison of Airepel HC with and without active ingredient anthraquinone

We established 4 cohorts consisting of 37–38 starlings per cage. We assigned 2 cages to each of 2 treatment groups (Airepel HC with castor oil with and without active ingredient anthraquinone) based on daily fecal deposits during D_{1-3}. We applied Airepel HC with castor oil to these perches with a CO_2 backpack sprayer. The Airepel HC without anthraquinone formulation was applied with a stiff paintbrush and/or putty knife. To compare the efficacy of the Airepel HC with castor oil to the Airepel HC without anthraquinone formulation, we conducted a Kruskal-Wallis test of the average fecal matter collected under treated perches. We otherwise replicated the methods of experiment 1.

Experiment 3: Comparison of Airepel HC with castor oil and inert formulation MS2

We established 4 cohorts consisting of 37–38 starlings per cage. We assigned 2 cages to each of 2 treatment groups (Airepel HC with castor oil and inert formulation MS2) based on daily fecal deposits during D_{1-3}. We applied Airepel HC with castor oil to these perches with a CO_2 backpack sprayer. The MS2 formulation was applied with a stiff paintbrush and/or putty knife. To compare the efficacy of the Airepel HC with castor oil to the MS2 formulation, we conducted a Kruskal-Wallis test of the average fecal matter collected under treated perches. We otherwise replicated the methods of experiment 1.

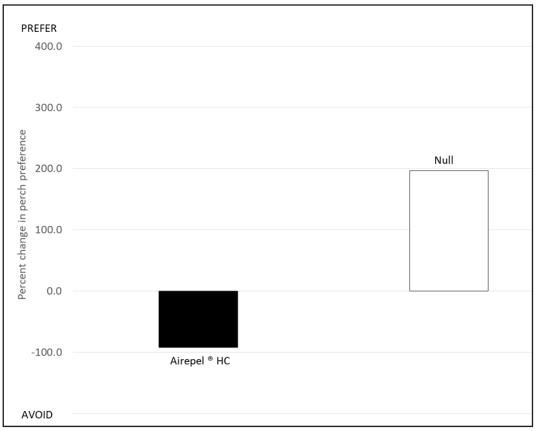

Figure 2. Results of experiment 1 testing with 3 cages of European starlings (*Sturnus vulgaris*) conducted in 2016 at the National Wildlife Research Center's Outdoor Animal Research Facility, Fort Collins, Colorado, USA. This figure depicts the percent change in perch preference from days 1–3 to days 4–6 of the test period ($\%\Delta = \{[(D_{4\text{-}6}) - (D_{1\text{-}3})]/(D_{1\text{-}3})\}$.

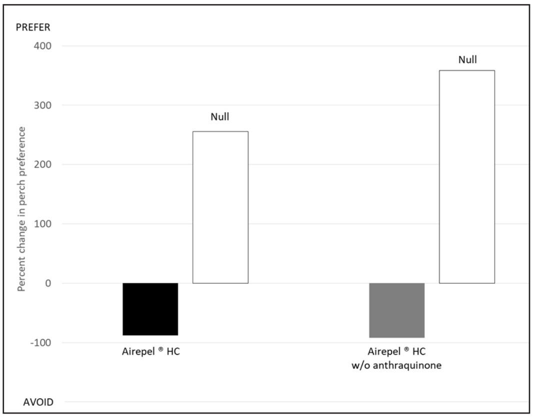

Figure 3. Results of experiment 2 testing with 4 cages of European starlings (*Sturnus vulgaris*) conducted in 2017 at the National Wildlife Research Center's Outdoor Animal Research Facility, Fort Collins, Colorado, USA. This figure depicts the percent change in perch preference from days 1–3 to days 4–6 of the test period ($\%\Delta = \{[(D_{4\text{-}6}) - (D_{1\text{-}3})]/(D_{1\text{-}3})\}$ for each of 2 test groups: Airepel® HC with castor oil and Airepel HC with castor oil without anthraquinone.

Results

Experiment 1: Evaluation of Airepel HC with castor oil as a perch repellent

On average, we applied 150,631 ± 5,147 mg anthraquinone/m^2 to each treated perch. During days 1–3, the average dry fecal material (g) collected beneath the untreated south and untreated north perch was 322.4 ± 63.8 g and 1,201.5 ± 114.3 g, respectively. The north perch was preferred during days 1–3 (z = -22.5, P = 0.0039). During days 4–6, the average dry fecal material collected beneath the untreated south and treated north perch was 1,233.5 ± 20.1 g and 109.4 ± 6.3 g, respectively. The south perch was preferred during days 4–6 (z = 22.5, P = 0.0039; Figure 2).

Experiment 2: Comparison of Airepel HC with and without active ingredient anthraquinone

On average, we applied 205,205 ± 1,144 mg anthraquinone/m^2 to each treated perch in group 1 and 164,253 ± 5,429 mg bentonite/m^2 to each treated perch in group 2. During days 1–3, the average fecal material collected beneath the untreated south and untreated north perch for group 1 was 579.1 ± 89.0 g and 388.5 ± 65.7 g and for group 2 was 667.9 ± 87.5 g and 368.3 ± 61.4 g, respectively. The south perch was preferred by groups 1 and 2 during days 1–3 (z = 7.5, P = 0.1563; z = 8.5, P = 0.0938). During days 4–6, the average fecal material collected beneath the treated south and untreated north perch for group 1 was 70.4 ± 9.3 g and 1,381.6 ± 105.0 g and for group 2 was 55.2 ± 19.8 g and 1,688.4 ± 149.9 g, respectively. The north perch was preferred by groups 1 and 2 during days 4–6 (z = -10.5, P = 0.0313; z = -10.5, P = 0.0313; Figure 3). We observed no difference between the treatments (i.e., Airepel HC with castor oil vs. Airepel HC with castor oil without anthraquinone; ($\chi^2[1] = 0.4286$, P = 0.5127).

Experiment 3: Comparison of Airepel HC with castor oil and inert formulation MS2

On average, we applied 81,052 ± 520 mg anthraquinone/m^2 to each treated perch in group 1 and 287 ± 20 g MS2 to each treated perch in group 2. During days 1–3, the average fecal material collected beneath the untreated south and untreated north perch for group 1 was 104.3 ± 62.1 g and 952.1 ± 141.2 g and for group 2 was 35.4 ± 15.9 g and 904.4 ± 32.7 g, respectively. The north perch was preferred by groups 1 and 2 during days 1–3 (z = -10.5, P = 0.0313; z = -10.5, P = 0.0313). During days 4–6, the average fecal material collected beneath the untreated south and treated north perch for group 1 was 758.3 ± 36.3 g and 127.0 ± 28.1 g and for group 2 was 535.6 ± 54.2 g and 19.8 ± 4.6 g, respectively. The south perch was preferred by groups 1 and 2 during days 4–6 (z = 10.5, P = 0.0313; z = 10.5, P = 0.0313;

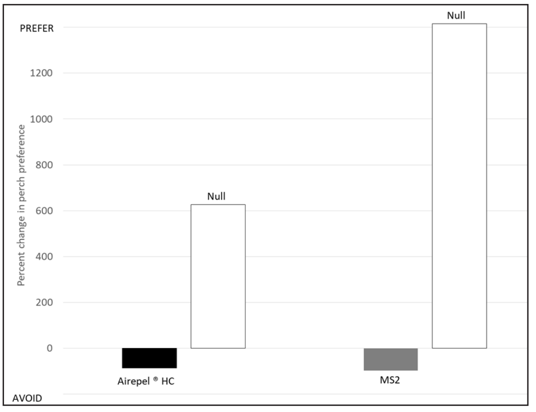

Figure 4. Results of experiment 3 testing with 4 cages of European starlings (*Sturnus vulgaris*) conducted in 2018 at the National Wildlife Research Center's Outdoor Animal Research Facility, Fort Collins, Colorado, USA. This figure depicts the percent change in perch preference from days 1–3 to days 4–6 of the test period (%Δ = $\{[(D_{4-6}) - (D_{1-3})]/(D_{1-3})\}$ for each of 2 test groups: Airepel® HC with castor oil and MS2.

Figure 5. Anthraquinone-treated and no-anthraquinone-treated aluminum perches used for repellent efficacy testing with European starlings (*Sturnus vulgaris*) at the National Wildlife Research Center's Outdoor Animal Research Facility, Fort Collins, Colorado, USA, 2016–2018. (A) Airepel® HC with castor oil formulation; (B) Airepel HC with castor oil without anthraquinone formulation; (C) MS2 formulation (*photos courtesy of H. McLean*).

Figure 4). We also observed less fecal accumulations beneath MS2-treated perches than those treated with Airepel HC with castor oil ($\chi^2[1] = 3.8571$, $P = 0.0495$).

Discussion

Airepel HC with castor oil, an anthraquinone-based repellent, shifted the perch preference of European starlings to the non-preferred perch in experiment 1 of our study. Airepel HC with castor oil produced a soft, dry-to-the-touch treatment (Figure 5), unlike most other surface-application repellents on the market. Anthraquinone products are most often used as feeding repellents (DeLiberto and Werner 2016). After experiment 1, we hypothesized that the unique texture (i.e., not the active ingredient) of the repellent formulation might have caused a decrease in fecal accumulation beneath treated perches.

We tested our hypothesis regarding the texture of surface-application repellents in experiment 2. The no-anthraquinone formulation contained the same inert ingredients as the Airepel HC with castor oil but replaced anthraquinone with bentonite clay. The Airepel HC with castor oil, without anthraquinone formulation, created a coating similar in texture to the Airepel HC with castor oil formulation. It had the same soft, dry-to-the-touch appearance, although the color was much darker (Figure 5). Both the Airepel HC with castor oil and Airepel HC with castor oil without anthraquinone formulations shifted the perch preference of European starlings to the non-preferred perch, with no statistical difference between the treatments. Based on observations of the birds' use of treated perches, the birds responded similarly to both treatments. We therefore concluded that texture might influence the efficacy of surface-application repellents. Both formulations used in experiment 2 contained castor oil. Castor oil is a viscous, non-volatile, and non-drying oil, and it therefore does not harden like some oils when exposed to air (Ogunniyi 2006). Thus, castor oil likely maintains the soft, malleable texture of the coating and may contribute to the efficacy of the formulations. We therefore hypothesized that other textures of surface-application repellents might also cause a decrease in fecal accumulation beneath treated perches.

We tested our hypothesis regarding other textures in experiment 3. The novel formulation (MS2) had a different appearance and consistency than the Airepel HC with castor oil formulation, with a tacky, oily texture that did not dry (Figure 5). MS2 resulted in a dramatic decrease in fecal accumulation beneath the treated perch, with virtually no feces collected beneath treated perches on days 5–6 of the test. Due to the tacky texture of the formulation, the transfer of the treatment to the feet of landing birds was inevitable. We observed some birds sliding on the angled surfaces of the perch, and even upon moving to the untreated perch, they were still unable to maintain sure footing

Figure 6. Airepel® HC with castor oil-treated aluminum perches used for repellent efficacy testing with European starlings (*Sturnus vulgaris*) at the National Wildlife Research Center's Outdoor Animal Research Facility, Fort Collins, Colorado, USA, 2016–2018. (A) Airepel HC with castor oil formulation before exposure to birds; (B) Airepel HC with castor oil formulation after exposure to birds showing minimal wear; (C) Airepel HC with castor oil formulation after exposure to birds showing moderate wear; (D) Airepel HC with castor oil formulation after exposure to birds showing heavy wear (*photos courtesy of H. McLean*).

Figure 7. MS2-treated aluminum perches used for repellent efficacy testing with European starlings (*Sturnus vulgaris*) at the National Wildlife Research Center's Outdoor Animal Research Facility, Fort Collins, Colorado, USA, 2016–2018. (A) MS2 formulation before exposure to birds; (B) MS2 formulation after exposure to birds showing minimal wear; (C) MS2 formulation after exposure to birds showing moderate wear (*photos courtesy of H. McLean*).

on angled surfaces. Birds were then observed cleaning their feet and wiping their bills on the untreated perch. Birds were not observed consuming either the Airepel HC or MS2 formulations. However, 1 bird from each treatment group (Airepel HC with castor oil and MS2) showed signs of illness, including piloerection and vomiting during the test. We observed no bird mortalities during or after testing.

Birds often flew to the treated perch when flushed by visual or audible disturbances during the test, regardless of repellent treatments. The treated perch was placed on the preferred side of each test cage, so birds were likely to flush to this perch regardless of repellent treatments. However, birds that did flush to the treated (Airepel HC with castor oil or Airepel HC with castor oil without anthraquinone) perch generally departed within 5–20 minutes. The MS2-treated perch was the exception to this observation. Birds generally avoided the MS2-treated perch even when flushed, and if they did land on the MS2-treated perch, they left within 1 minute. During the test period, birds in general (and in all treatments) made more use of alternate perches within the test cage (i.e., not using either treated or untreated perches), including the walls of the cage and the rims of food and water bowls. Starlings also utilized an alternate perch site (e.g., floor) instead of treated or untreated perches in previous repellent studies (Scott and Schafer 1988, Clark 1997). Brown-headed cowbirds similarly avoided untreated perches and perches treated with anthraquinone, preferring the use of the floor (Ballinger 2001).

Perch repellents have had varied efficacy when evaluated based on perch use (i.e., perch occupancy). Avery et al. (unpublished data) evaluated bird use of anthraquinone-treated and untreated perches during 6 30-minute test periods. These experiments showed no statistical difference between European starling use (mean number of birds per perch per minute) of anthraquonine-treated and untreated perches. However, for 3 other species tested, the use of untreated perches was at least twice that of treated perches (Avery et al., unpublished data). Stock and Haag-Wackernagel (2014) evaluated a contact repellent (capsaicin) and an optical repellent (peppermint oil and cinnamon oil) with feral pigeons (*Columba livia*). While both gels reduced the number of approaches by feral pigeons and the amount of time that pigeons spent on experimental shelves, neither repellent eliminated the use of the experimental shelves by pigeons (as claimed by manufacturers). Based on observations of bird use of treated perches (i.e., occupancy), treatments in our study would have had similar results. Birds in all treatment groups occupied the treated perch, although the use of the untreated perch was greater than that of the treated perch. However, interpretation of these observations is dependent on what behavior one is trying to modify. If the elimination of bird presence at a site is the primary goal, then exclusion methods (e.g., netting) may be a better-suited management tool. However, if a reduction in fecal accumulation is the primary goal, then a surface formulation like those evaluated in this study would be a useful management tool.

One of the main disadvantages of surface-application repellents is the accumulation of dust or moisture on the treatment rendering them ineffective. Stock and Haag-Wackernagel (2014) describe insects, feathers, and fecal material coating, both treatments evaluated in their testing. During 3 days of testing, the appearance of both Airepel HC with castor oil and Airepel HC with castor oil without anthraquinone treatments was similar to the appearance of the initial treatment, and no foreign items became stuck in the formulations during our experiments. However, particularly in experiment 3, the Airepel HC with castor oil treatment had worn off the portion of the perch most often utilized by birds (Figure 6). The MS2 treatment evaluated in experiment 3 had also worn thinner by the end of test day 6, with bird feathers becoming stuck in the treatment (Figure 7). Despite wear of the repellent formulations from the aluminum perches, we did not observe repellent treatments on the feathers or the impediment of flight among our test subjects. Previous studies have shown that some tactile repellents can indiscriminately capture non-target animals (Reidinger and Libay 1979). Tactile repellents can also stick to flight feathers, affecting the operation of the flight feathers, especially of smaller birds, leading to death (Scott and Schafer 1988). The benefits of a formulation comprising only inert ingredients include less risk to applicators and non-target species.

Management implications

Our findings suggest that the texture of surface application repellents may be as important as repellent active ingredients contained in the formulation. Unlike most surface-application repellents that can accumulate dust, moisture, and other debris, the Airepel HC with castor oil and Airepel HC with castor oil without anthraquinone formulations had a dry-to-the-touch surface that did not accumulate debris. A surface-application repellent of this kind would be advantageous in field conditions, especially when compared to commercially available surface-application treatments. These formulations are also comprised of inert ingredients, thereby minimizing the mortality risk to both target and non-target species.

Acknowledgments

We thank the National Wildlife Research Center (NWRC) animal care staff for their assistance with this study, including animal care during quarantine and holding and assistance with cleaning cages during testing. We would also like to thank A. Mangan, J. Jackson, and C. Suckow for their assistance in conducting these experiments. Comments provided by G. Linz, HWI associate editor, and 2 anonymous reviewers greatly improved the manuscript. This research was supported by the U.S. Department of Agriculture's NWRC.

Literature cited

Ballinger, K. E., Jr. 2001. Method of deterring birds from plant and structural surfaces. U.S. Patent 6,328,986.

Belant, J. L., P. P. Woronecki, R. A. Dolbeer, and T. W. Seamans. 1998. Ineffectiveness of five commercial deterrents for nesting starlings. Wildlife Society Bulletin 26:264–268.

BirdLife International. 2016. Common starling *Sturnus vulgaris*. The IUCN Red List of Threatened Species 2016: e.T22710886A87847984, International Union for Conservation of Nature, Gland Switzerland, <http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22710886A87847984.en>. Accessed March 6, 2018.

Caccamise, D. F., and D. W. Morrison. 1988. Avian communal roosting: a test of the "patch-sitting" hypothesis. Condor 90:453–458.

Carlson, J. C., A. B. Franklin, D. R. Hyatt, S. E. Pettit, and G. M. Linz. 2011. The role of starlings in the spread of *Salmonella* within concentrated animal feeding operations. Journal of Applied Ecology 48:479–486.

Clark, L. 1997. Dermal contact repellents for starlings: foot exposure to natural plant products. Journal of Wildlife Management 61:1352–1358.

Clark, L. 1998. Review of bird repellents. Proceedings of the Vertebrate Pest Conference 18:330–337.

Clark, L. 2014. Disease risks posed by wild birds associated with agricultural landscapes. Pages 139–155 *in* K. R. Matthews, G. M. Sapers, and

C. P. Gerba, editors. The produce contamination problem. Academic Press, Boston, Massachusetts, USA.

Cummings, J. L., P. A. Pochop, J. E. Davis, Jr., and H. W. Krupa. 1995. Evaluation of ReJeX-iT AG-36 as a Canada goose grazing repellent. Journal of Wildlife Management 59:47–50.

DeLiberto, S. T., and S. J. Werner. 2016. Review of anthraquinone applications for pest management and agricultural crop protection. Pest Management Science 72:1813–1825.

Devers, P., P. Reichert, and R. Poche. 1998. Field trial using Flight Control as a repellent for Canada goose (*Branta canadensis*) control in Fort Collins, Colorado. Proceedings of the Vertebrate Pest Conference 18:345–349.

Fernández-Juricic, E. 2016. The role of animal sensory perception in behavior-based management. Pages 149–175 *in* D. Saltz and O. Berger-Tal, editors. Conservation behavior: applying behavioral ecology to wildlife conservation. Cambridge University Press, Cambridge, United Kingdom.

Fitzwater, W. D. 1982. Bird limes and rat glues—sticky situations. Proceedings of the Vertebrate Pest Conference 10:17–20.

Gaukler, S. M., G. M. Linz, J. S. Sherwood, N. W. Dyer, W. J. Bleier, Y. M. Wannemuehler, L. K. Nolan, and C. M. Logue. 2009. *Eschericiha coli*, *Salmonella*, and *Mycobacterium avium* subsp. paratuberculosis in wild European starlings at a Kansas cattle feedlot. Avian Diseases 53:544–551.

Geluso, K., and J. P. Hayes. 1999. Effects of dietary quality on basal metabolic rate and internal morphology of European starlings (*Sturnus vulgaris*). Physiological and Biochemical Zoology: Ecological and Evolutionary Approaches 72:189–197.

Gingrich, J. B., and T. E. Osterberg. 2003. Pest birds: biology and management at food processing facilities. Pages 317–339 *in* Y. H. Hui, B. L. Bruinsma, J. R. Gorham, W. K. Nip, P. S. Tong, and P. Ventresca, editors. Food plant sanitation. Marcel Dekker, New York, New York, USA.

Giunchi, D., Y. V. Albores-Barajas, N. E. Baldaccini, L. Vanni, and C. Soldatini. 2012. Feral pigeons: problems, dynamics, and control methods. Pages 215–240 *in* M. L. Larramendy and S. Soloneski, editors. Integrated pest management and pest control: current and future tactics. InTech, Rijeka, Croatia.

Glahn, J. F., J. R. Mason, and D. R. Woods. 1989. Dimethyl anthranilate as a bird repellent in livestock feed. Wildlife Society Bulletin 17:313–320.

Glahn, J. F., A. R. Stickley, Jr., J. F. Heisterberg, and D. F. Mott. 1991. In my experience: impact of roost control on local urban and agricultural blackbird problems. Wildlife Society Bulletin 19:511–522.

Haag-Wackernagel, D. 1995. Regulation of the street pigeon in Basel. Wildlife Society Bulletin 23:256–260.

Jackson, S. J., S. W. Nicolson, and C. N. Lotz. 1998. Sugar preferences and "side bias" in cape sugarbirds and lesser double-collared sunbirds. Auk 115:156–165.

Jernelöv, A. 2017. The long-term fate of invasive species. Aliens forever or integrated immigrants with time? Springer International, Cham, Switzerland.

LeJeune, J. T., J. Homan, G. M. Linz, and D. L. Pearl. 2008. Role of the European starling in the transmission of *E.Coli* O157 on dairy farms. Proceedings of the Vertebrate Pest Conference 23:31–34.

Lucas, A. M., and P. R. Stettenheim. 1972. Avian anatomy: integument. Part II. U.S. Government Printing Office, Washington D.C., USA.

Mason, J. R., and L. Clark. 1995*a*. Avian repellents: options, modes of action, and economic considerations. Pages 371–391 *in* J. R. Mason, editor. Repellents in wildlife management. Colorado University Press, Fort Collins, Colorado, USA.

Mason, J. R., and L. Clark. 1995*b*. Evaluation of methyl anthranilate and activated charcoal as snow goose grazing deterrents. Crop Protection 14:467–469.

Medhanie, G. A., D. L. Pearl, S. A. McEwen, M. T. Guerin, C. M. Jardine, J. Schrock, and J. T. LeJeune. 2017. Spatial clustering of *Escherichia coli* with reduced susceptibility to cefotaxime and ciprofloxacin among dairy cattle farms relative to European starling night roosts. Zoonoses Public Health 64:204–212.

Mineau, P. 2011. Barking up the wrong perch: why we should stop ignoring nondietary routes of pesticide exposure in birds. Integrated Environmental Assessment and Management 7:297–299.

Ogunniyi, D. S. 2006. Castor oil: a vital industrial raw material. Bioresource Technology 97:1086–1091.

Pimentel, D., L. Lach, R. Zuniga, and D. W. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53–65.

Reidinger, R. F., Jr., and J. L. Libay. 1979. Perches coated with glue reduce bird damage in rice-field plots. Proceedings of the Bird Control Seminar 26:201–206.

Sanad, Y. M., G. J. Closs, A. Kumar, J. T. LeJeune, and G. Rajashekara. 2013. Molecular epidemiology and public health relevance of *Campylobacter* isolated from dairy cattle and European starlings in Ohio, USA. Foodborne Pathogen Diseases 10:229–236.

Scott, E. J., and E. W. Schafer, Jr. 1988. A test method that evaluates avian perch repellents. Pages 52–55 *in* S. A. Shumake, and R. W. Bullard, editors. Vertebrate pest control and management materials. Volume 5. American Society for Testing and Materials, Philadephia, Pennsylvania, USA.

Seamans, T. W., J. A. Martin, and J. L. Belant. 2013. Tactile and auditory repellents to reduce wildlife hazards to aircraft. Pages 37–46 *in* T. L. DeVault, B. F. Blackwell, and J. L. Belant, editors. Wildlife in airport environments: preventing animal–aircraft collisions through science-based management. Johns Hopkins University Press, Baltimore, Maryland, USA.

Stock, B., and D. Haag-Wackernagel. 2014. Effectiveness of gel repellents on feral pigeons. Animals 4:1–15.

Thompson, W. L., and E. L. Coutlee. 1963. The biology and population structure of starlings at an urban roost. Wilson Bulletin 75:358–372.

Werner, S. J., G. M. Linz, S. K. Tupper, and J. C. Carlson. 2010. Laboratory efficacy of chemical repellents for reducing blackbird damage in rice and sunflower crops. Journal of Wildlife Management 74:1400–1404.

Werner, S. J., and F. D. Provenza. 2011. Reconciling sensory cues and varied consequences of avian repellents. Physiology and Behavior 102:158–163.

White, S. B., R. A. Dolbeer, and T. A. Bookhout. 1985. Ecology, bioenergetics, and agricultural impacts of a winter-roosting population of blackbirds and starlings. Wildlife Monographs 93:3–42.

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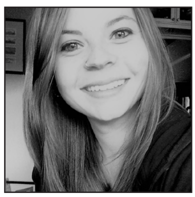

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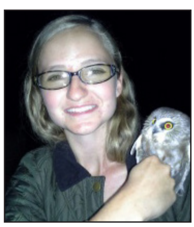

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