Use of activated charcoal and other particulate substances as feed additives to suppress bird feeding

J. Russell Mason* and Larry Clark

US Department of Agriculture, Animal and Plant Health Inspection Service, Denver Wildlife Research Center, c/o Monell Chemical Senses Center, 3500 Market Street, Philadelphia, PA 19104–3308, USA

Osmotic strength is a function of particle number. The experiments described here were designed to test whether the consumption of a large number of small particles might induce strong osmotic effects that, in turn, could induce food avoidance learning. The experiments also evaluated whether the abrasiveness of fine particulates or their ability to act as organic adsorbants could mediate or contribute to the avoidance of adulterated diets. In experiment 1, captive European starlings (*Sturnus vulgaris*) were given two-cup tests between plain chow and chow adulterated with activated charcoal or Anjan-activaid, a product containing large amounts of activated charcoal. Both adulterants decreased consumption of chow at concentrations ranging from 0.63% to 5.0% (w/w). In experiment 2, starlings were given two-cup tests between plain chow and chow adulterated with quartz sand. At the conclusion of the experiment, the gastrointestinal tracts of test birds and other (control) birds were examined for lesions consistent with abrasion. Quartz sand decreased feeding at concentrations of 5.0 and 2.5%, but no evidence of lesions or inflammation was observed. In experiment 3, activated charcoal, Anjan-activaid, quartz sand, and calcium sulfate were placed in dialysis tubing and the tubes were immersed in water to test for differences in osmotic strength: no differences were found. In experiment 4, starlings were given plain chow and feed adulterated with calcium sulfate to test whether organic adsorption might contribute to repellency; unlike activated charcoal, Anjan-activaid, or sand, calcium sulfate is a poor organic adsorbent. No food avoidance was observed, consistent with the hypothesis that adsorbance was important for the effects observed in experiments 1 and 2. Although caution is necessary when extrapolating from the laboratory to the field, these results have testable practical implications: for example, activated charcoal or Anjan-activaid might be used as bird-repellent livestock feed additives and either of these substances or quartz sand might be useful as bird-repellent additives to landfill covers or as repellents applied to crops.

Keywords: activated charcoal; bird; repellent; starling; *Sturnus vulgaris*

Few effective chemicals are legally available for the control of avian depredation (Mason and Clark, 1992). As a result, there is increasing interest in the development of new repellent products such as anthranilate derivatives (e.g. Mason, Adams and Clark, 1989), cinnamic acid derivatives (Crocker and Perry, 1990; Crocker *et al.*, 1993) *d*-pulegone (Mason, 1990), cucurbitacin (Mason and Turpin, 1990), fungicides (Avery and Decker, 1991) and clays (Decker and Avery, 1990).

Recently, Brugger and her colleagues (Brugger and Nelms, 1991; Brugger, 1992; Brugger, Nol and Phillips, 1993) hypothesized that sucrose might represent a promising repellent for some avian species. Ingestion of high sucrose concentrations may cause food avoidance learning, mediated by sucrase deficiencies (Martinez del Rio *et al.*, 1988; Martinez del Rio and Stevens, 1989) and/or the negative osmotic consequences of ingesting large quantities of sugar (Clark and Mason, 1993).

*To whom correspondence should be addressed

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Osmotic strength is a function of particle number (Schmidt-Nielson, 1983). Accordingly, we designed the present experiments to test the proposition that consumption of a large number of small particles might induce strong osmotic effects which, in turn, could induce food avoidance learning (experiments 1, 3). We also examined the possibility that the abrasiveness of fine particulates (experiment 2), or their ability to act as organic adsorbants (experiment 4) could mediate and/or contribute to the avoidance of adulterated diets.

Materials and methods

Chemicals

Several fine particulate substances were selected for evaluation. Anjan-activaid was provided by Pickenhagen Partners (Geneva, Switzerland). This product is mainly 14–60 mesh activated charcoal, combined with a small amount of a proprietary binder. Activated charcoal (14–60 mesh; CAS No. 64365-11-

3), white quartz sand (50–70 mesh; CAS No. 14808-60-7), and calcium sulfate (14–60 mesh; CAS No. 10101-41-4) were purchased from Sigma Chemical Company (St Louis, MO, USA).

Birds

Fifty-nine starlings (*Sturnus vulgaris*) were decoy-trapped in Sandusky, Ohio, and shipped to the Monell Chemical Senses Center. Upon arrival, the birds were weighed and individually caged (dimensions 61 × 36 × 41 cm) under a 12 h:12 h light:dark cycle. During a 2-week period of adaptation to laboratory conditions (e.g. captivity, feeding and maintenance routines, light cycles), birds were given free access to Purina Flight Bird Conditioner (referred to below as chow; Purina Mills, St Louis, MO, USA) and tapwater.

Experiment 1: osmotic effects; Anjan-activaid and activated charcoal

Twenty-six birds were randomly selected. On each of 4 pretreatment days, all birds were presented with two cups (8 cm diameter), each containing 20 g of plain chow at 08:00 . Each cup had a metal lid with a 3.8 cm hole in the centre through which the birds could feed. This lid kept faeces from contaminating chow, and minimized spillage. At 10:00, the chow remaining in each cup was weighed. This 2 h test period was used so that the data obtained would be readily comparable with data collected for other repellent substances (e.g. anthranilate derivatives, Mason *et al.*, 1989; pulegone, Mason, 1990). Spillage was minimal. It was not measured, both for practical reasons (e.g. accurately separating spillage from each cup), and because the degree of spillage typically reflects consumption (e.g. Mason *et al.*, 1991). From 10:00 to 17:00, birds were permitted free access to chow and water. At 17:00, chow was removed from the cages, and birds were food-deprived overnight to ensure measurable consumption during test periods. This food deprivation regime remained in effect throughout the experiment.

After the fourth pretreatment session, birds were assigned to two cohorts ($n = 13$ per cohort) counterbalanced on the basis of consumption. A 4-day treatment period began the next day. One cohort was presented with chow adulterated with various concentrations of Anjan-activaid, while the other was presented with chow adulterated with various concentrations of activated charcoal (see below). Stimulus samples in this and subsequent experiments were prepared by thoroughly mixing the adulterants with chow just before each test session. Little, if any, settling occurred.

On each treatment day, each bird received a two-cup test. The chow in one cup was adulterated with 5.0, 2.5, 1.25 or 0.63% (w/w) of Anjan-activaid (cohort 1) or activated charcoal (cohort 2); the other cup contained plain chow. The order in which the test concentrations were presented to each bird, as well as the side of the cage on which the adulterated chow was presented, was randomly determined. As in pretreatment, consumption was recorded at 10:00. Birds were permitted free access to chow and water from 10:00 to 17:00. Birds were food-deprived overnight.

Experiment 2: abrasiveness; white quartz sand

Thirteen experimentally naïve birds were selected randomly and adapted to the food deprivation regime for 2 weeks. Pretreatment immediately followed: on each of 4 days, the birds were given two-cup feeding tests for 2 h (08:00–10:00) with plain chow in each cup. Consumption was measured as described in experiment 1. From 10:00 to 17:00, chow and water were freely available. Birds were food-deprived overnight throughout the experiment.

A 4-day treatment period began immediately following the last pretreatment day. At 08:00 on each treatment day, all birds were given two cups. One cup contained chow adulterated with various concentrations of quartz sand, while the other cup contained plain chow. The sand concentrations were 5.0, 2.5, 1.25, and 0.63% (w/w). The order in which these concentrations were presented to each bird was randomly determined. At 10:00, the amount of chow remaining in each cup was weighed. Birds were permitted free access to chow and water from 10:00 to 17:00. Immediately after the fourth treatment test period, all birds were humanely killed by carbon dioxide inhalation. Five experimentally naïve birds also were killed. Gastrointestinal tracts were removed from all birds immediately after killing and examined microscopically for lesions and/or inflammation.

Experiment 3: osmotic effects; dialysis

Four 2 g samples of Anjan-activaid, four 2 g samples of activated charcoal, four 2 g samples of quartz sand, and four 2 g samples of calcium sulfate (see experiment 4, below) were loaded into 16 sections (3 cm) of seamless dialysis tubing (40 mm flat width, 25 mm diameter; Sigma Chemical Company). Both ends of each tube were tied tightly, and then the tubes were weighed and immersed in deionized distilled water. After 2 h of immersion, the tubes were re-weighed. Differences between pre- and postimmersion weights were taken as a measure of osmotic strength (Schmidt-Nielsen, 1983).

Experiment 4: organic adsorbance; calcium sulfate

Twenty experimentally naïve birds were selected randomly and adapted to the food deprivation regime used in experiments 1 and 2. Deprivation remained in effect throughout the experiment. After 2 weeks, all birds were given two-cup pretreatment tests for 2 h on each of 4 days between 08:00 and 10:00. At the end of the pretreatment period, the birds were assigned to four groups ($n = 5$ per group) counterbalanced on the basis of mean pretreatment consumption. A 4-day treatment period immediately followed. All birds were presented with two cups, one containing chow adulterated with calcium sulfate and the other containing plain chow. Each group was presented with a different calcium sulfate concentration. Group 1 was presented with 5.0% (w/w) calcium sulfate, group 2, 2.5% calcium sulfate, group 3, 1.25% calcium sulfate, and group 4, 0.63% calcium sulfate. At the end of each test session (10:00), the chow remaining in each cup was weighed.

Calcium sulfate was chosen as the test substance for two reasons: first, its particle size (14–60 mesh) overlapped those of Anjan-activaid and activated charcoal; second, unlike the latter substances (Sugisawa and Hirose, 1981; product label information, Pickenhagen Partners, Geneva, Switzerland), calcium sulfate is a poor organic adsorbant (Budavarai *et al.*, 1989).

Analysis

Experiment 1 treatment period data were evaluated in a three-factor analysis of variance (ANOVA). The independent factor in this analysis was cohort (two levels), while the repeated measures were concentrations (four levels) and cups (two levels).

Treatment period data of experiments 2 and 4 were evaluated in three-factor ANOVAs. The independent factor in these analyses was concentration (four levels) while the repeated factors were treatment days (four levels) and cups (two levels).

The results of experiment 3 (dialysis) were not subjected to ANOVA because mean weight changes among sample types overlapped.

Subsequent to all ANOVAs, Tukey tests (Winer, 1971) were used to isolate significant differences ($p < 0.05$) among means.

Results

Experiment 1: Anjan-activaid and activated charcoal

The ANOVA summary table is presented in *Table 1*. Overall, significantly less adulterated chow was consumed by *S. vulgaris* (*Figure 1*). In addition, there were significant interactions between cohorts and concentrations, concentrations and cups and among cohorts, concentrations and cups. Post-hoc examination of the cohort × concentrations interaction showed that overall consumption (treated and untreated chow combined) during presentations of 5.0 or 2.5% Anjan-activaid was significantly greater than overall consumption during presentations of 5.0 or 2.5% activated charcoal. Examination of the concentrations × cups interaction showed that consumption of adulterated chow was inversely related to the concentration of the adulterants. Examination of the three-way interaction among cohorts, concentrations and cups indicated that consumption of chow at all concentrations of Anjan-activaid and activated charcoal was less than that of plain chow. Post-hoc tests showed that there were no differences in consumption of chow adulterated with the various concentrations of activated charcoal: all were avoided to the same extent. This was not the case for Anjan-activaid: consumption of 5.0 or 2.5% adulterated feed was significantly less than consumption of 1.25 or 0.63% adulterated feed.

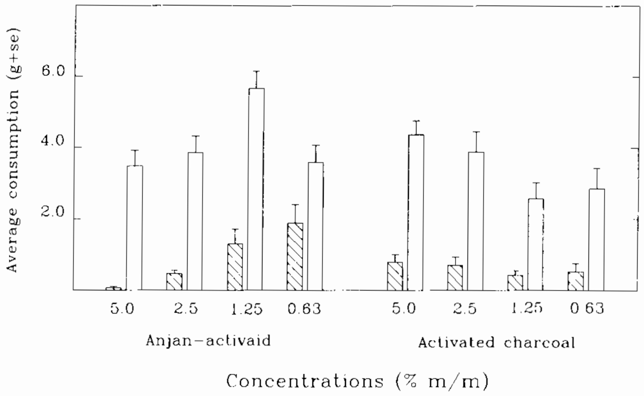

Figure 1. Average consumption of chow adulterated (▨) with Anjan-activaid (left) or activated charcoal (right) vs mean consumption of plain chow (□) in two-cup tests by penned starlings. Capped vertical bars represent standard errors of the means; % m/m = percentage [mass/mass (weight/weight)]

Table 1. Three-factor ANOVA of results of experiment 1 (the osmotic effects of Anjan-activaid and activated charcoal when added to the food of European starlings)[a]

Comparisons	Factor	SS	d.f.	MS	*F*	*p*
Between groups	Cohort	14.28	1	14.28	3.48	0.07
	Error	98.50	24	4.10		
Within groups	Concentration	3.27	3	1.09	2.69	0.05
	Cohort × concentration	59.84	3	19.95	49.24	0.00001
	Error	29.17	72	0.40		
	Cup	472.51	1	472.51	71.89	0.00001
	Cohort × cup	2.14	1	2.14	0.33	
	Error	157.73	24	6.57		
	Concentration × cup	17.76	3	5.92	3.81	0.013
	Cohort × concentration × cup	15.34	3	5.11	3.29	0.025
	Error	111.77	72	1.55		
	Total	982.30	207			

[a]The independent factor was cohort (two levels); the repeated measures were concentrations (four levels) and cups (two levels)

Experiment 2: white quartz sand

The summary table for the ANOVA is presented in *Table 2*. There was a significant difference in consumption of chow with and without white quartz sand; consumption of adulterated chow was less than that of plain chow (*Figure 2*). Furthermore, overall consumption (adulterated and plain chow combined) decreased over days. Post-hoc examination of a significant interaction between concentrations and cups showed that consumption of 5.0 or 2.5% (but not 1.25 or 0.63%) sand-adulterated chow was significantly less than that of plain chow. Post-mortem examinations failed to reveal evidence of lesions or inflammation in either experimental or naïve birds.

Experiment 3: osmotic effects; dialysis

There were no apparent differences among materials in osmotic strength. Average weight changes (± standard errors of the means) were: Anjan-activaid, 1.78 ± 0.32 g; activated charcoal, 1.65 ± 0.22 g; quartz sand, 1.73 ± 0.31 g; calcium sulfate, 1.72 ± 0.28 g.

Experiment 4: calcium sulfate

The ANOVA failed to reveal any significant differences ($p > 0.25$; *Figure 3*). No concentration of calcium sulfate reduced consumption of adulterated chow relative to consumption of plain chow, and there were no differences in consumption among days ($p > 0.25$).

Discussion

Anjan-activaid, a product containing activated charcoal, and activated charcoal, *per se*, are significantly repellent to starlings when presented in two-cup tests at concentrations ranging from 0.625 to 5.0% (w/w). The former material appears to be more repellent than the latter at high concentrations (5.0 and 2.5%), but the converse seems to be true at lower concentrations (1.25 and 0.63%). At least three plausible explanations can be given for these results: first, repellency could be mediated by negative osmotic effects in the gut; second, repellency could be mediated by the abrasiveness of these fine particles in the oral cavity or gastrointestinal tract; third, repellency could be mediated by the adsorption of organic materials from ingested food by the adulterants. Adsorption would lower the nutritive value of the food. Each of these plausible explanations is discussed below.

The results of experiment 3 were inconsistent with the first hypothesis, i.e. that osmotic effects contributed to repellency. Even though Anjan-activaid and activated charcoal were more repellent than quartz sand, and all three of these substances were more repellent than calcium sulfate, weight changes (i.e. osmotic strength) for all four adulterants were similar.

The results of experiment 2 were inconsistent with the second hypothesis, i.e. that avoidance was influenced by the abrasiveness of particles in the oral cavity or gastrointestinal tract. Only the two high sand concentrations (5.0 and 2.5%) were avoided, and post-mortem examinations did not reveal inflammation or lesions consistent with abrasion in experimental birds.

The results of experiment 4 did support the third hypothesis, i.e. that organic adsorbance contributed to

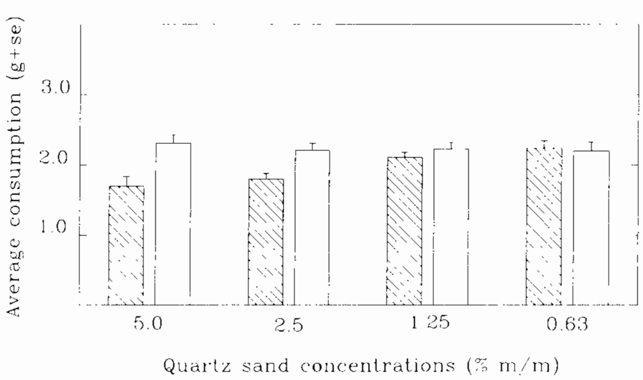

Figure 2. Average consumption of chow adulterated with quartz sand (▨) vs consumption of plain chow (□) in two-cup tests by penned starlings. Capped vertical bars represent standard errors of the means; % m/m = % w/w

Table 2. Three-factor ANOVA of results of experiment 2 (the effects of white quartz sand when added to the food of European starlings)[a]

Comparisons	Factor	SS	d.f.	MS	F	p
Between groups	Concentration	2.40	3	0.80	0.96	0.07
	Error	16.69	20	0.83		
Within groups	Day[b]	199.63	3	66.54	618.66	0.00001
	Concentration × day	1.19	9	0.13	1.23	0.29
	Error	6.45	60	0.11		
	Cup	1.58	1	1.58	6.76	0.016
	Concentration × cup	2.05	3	0.68	3.93	0.05
	Error	4.67	20	0.23		
	Day × cup	1.83	3	0.61	1.55	0.21
	Concentration × day × cup	6.84	9	0.76	1.92	0.07
	Error	23.74	60	0.39		
	Total	267.08	191			

[a]The independent factor was concentration (four levels); the repeated measures were treatment days (four levels) and cups (two levels); [b]day = treatment day

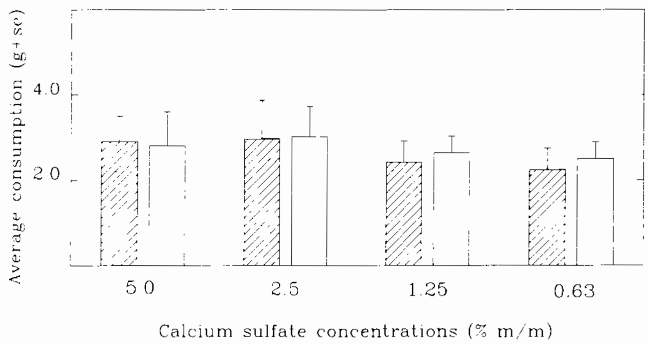

Figure 3. Average consumption of chow adulterated with calcium sulfate (▨) vs consumption of plain chow (□) in two-cup tests by penned starlings. Capped vertical bars represent standard errors of the means; % m/m = % w/w

avoidance of Anjan-activaid, activated charcoal and sand-adulterated food. In addition, Anjan-activaid and activated charcoal are better adsorbants than sand (Sugisawa and Hirose, 1981; Budavari *et al*, 1989; Pickenhagen Partners, Geneva, Switzerland), and this difference could explain the superior repellency of the former materials.

Avoidance of Anjan-activaid, activated charcoal, or sand could reflect the sensory texture or 'mouth-feel' of these substances. In addition, visual differences between treated and untreated foods may have contributed to avoidance of adulterated chow. Although these possibilities cannot be discounted on the basis of our data, we do not believe that these factors were important. First, there was considerable overlap in particle size among the adulterants examined, and we believe that this overlap would contribute to perceptually similar textural characteristics. Although particle hardness also contributes to texture, there was no obvious relationship between hardness and avoidance responding. Anjan-activaid and activated charcoal were relatively more effective repellents than the hardest substance, quartz sand, and all three substances were more effective than calcium sulfate, a material that appeared to us to be as hard as activated charcoal. With regard to visual cues, although Anjan-activaid and activated charcoal darkened food samples whereas calcium sulfate lightened them, only the former substances influenced consumption. Moreover, activated charcoal was similarly avoided at all concentrations, whereas the aversiveness of Anjan-activaid was concentration dependent. Although it is true that birds sometimes transiently avoid aposematic colours (i.e. red, orange; Reidinger and Mason, 1983), there is no evidence that black or white are similarly avoided.

Management implications

Although caution is necessary in extrapolating from the laboratory to the field, the findings reported here suggest practical, testable applications for Anjan-activaid, activated charcoal and fine quartz sand. For example, Anjan-activaid or activated charcoal might be useful as bird-repellent livestock feed additives. In addition to bird control, waste odour abatement might be achieved. Although organic adsorbants in the diets of some livestock (e.g. ruminants) could have deleterious effects on nutrients for essential gut micro-organisms, it is also possible that such materials could alter gut chemistry in ways that would optimize conditions for digestion (C. Scanes, Rutgers University, personal communication). Ruminants have been fed activated charcoal to minimize the absorption of pesticides from diet (Wilson, Cook and Emery, 1968), and sheep have been fed diets containing 5.0% (w/w) activated charcoal for long periods (84 days) without apparent ill effects (Crookshank, Smalley and Radeleff, 1972). A field test of activated charcoal in livestock diets, as well as an investigation of the effects of these materials on the digestive efficiency of livestock, appear warranted.

A second use of Anjan-activaid, activated charcoal or quartz sand might be as bird repellents (and odour control materials) at landfills. For example, these materials could be incorporated into landfill covers (e.g. Concover, Newastecon Inc., Perrysburg, OH, USA) to prevent birds from penetrating and disrupting these covers during foraging attempts.

A third use of Anjan-activaid, activated charcoal or quartz sand might be in combination with agricultural adhesives for application to food (e.g. fruit), or non-food (e.g. turf) crops. Unlike other substances that repel birds (e.g. methyl anthraniliate, *d*-pulegone), none of the three substances has a flavour that would contaminate the flavour of the crop.

Overall, Anjan-activaid, activated charcoal and quartz sand are metabolically and environmentally inert. These substances should present few, if any, hazards to wildlife or the environment. Because registration costs for these particulates would be minimal relative to the registration costs of other pesticides, and because at least one – activated charcoal – is approved for human consumption (e.g. Barnhart, 1989), additional laboratory and field experiments appear warranted.

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