MICROENCAPSULATED LITHIUM CHLORIDE BAIT AVERSION DID NOT STOP COYOTE PREDATION ON SHEEP

RICHARD J. BURNS, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Utah State University UMC 52, Logan, UT 84322

Abstract: Experiments were conducted with microencapsulated lithium chloride to find a concentration that would produce optimum sheep-bait aversion and to test the transfer of the bait aversion to sheep-killing aversion in naive (no sheep-killing experience) and sheep-killing coyotes (*Canis latrans*). Lithium chloride at 1.08 g/500 g of sheep flesh, fed to coyotes at a rate of 500 g of treated flesh/10 kg of coyote body weight, produced the strongest bait aversion of the 4 concentrations tested. However, after showing strong aversion to baits fed at the above concentration, most coyotes (both naive and experienced) killed and fed on lambs, showing no transfer from bait aversion to predation aversion.

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Conditioned taste aversion has been promoted as a method to prevent coyotes from killing sheep. The method entails treating mutton baits with a strong emetic, lithium chloride (LiCl), and placing the baits on sheep range. Presumably, coyotes find and eat the baits, become ill, and subsequently avoid sheep because they have learned to associate mutton flavor and sheep with sickness.

The application of LiCl-conditioned taste aversion to reduce coyote predation on sheep originated with Gustavson et al. (1974). Subsequently, Gustavson et al. (1976, 1982), Ellins et al. (1977), and Ellins and Catalano (1980) reported that LiCl baiting appeared to be effective. However, other investigators obtained negative results. Griffiths et al. (1978) reviewed prior work on the subject and concluded that no valid judgment could be made about the effectiveness of LiCl for controlling coyote predation on sheep.

Recent field studies and experiments (Burns 1980, Burns and Connolly 1980, Bourne and Dorrance 1982) indicated that conditioning with LiCl baits did not stop coyotes from killing prey. Bourne and Dorrance (1982) reported that LiCl baits, and probably bait aversion, did not measurably reduce coyote predation of lambs on farms with LiCl baits compared to farms with placebo baits (no LiCl). Burns (1980) demonstrated that, with high LiCl doses, the salt flavor of LiCl interfered with the ability of coyotes to form aversions to baits and prey killing, a finding supported by Conover (1982). Later, Burns and Connolly (1980) produced a black-tailed jack rabbit (*Lepus californicus*) bait aversion with a lower dose of LiCl that reduced salt-taste interference. After showing bait aversion, however, coyotes continued to kill and eat jack rabbits. Coyotes easily discriminated between baits and live prey and after killing, fed, probably because they detected no LiCl flavor and odor. Ellins and Martin (1981) reported that coyotes could use LiCl odor to discriminate between treated and untreated meat.

Reducing or eliminating the odor and flavor cues in LiCl baits should increase the likelihood of bait aversion to pure prey flesh, and thereby increase the likelihood that bait aversion would transfer to a prey-killing aversion. It has also been suggested that specific prey-killing experience before eating LiCl-treated baits might interfere with the formation of prey-killing aversion in coyotes (Conover et al. 1977, Burns 1980). This interference might oc-

cur by the same process that causes reduced conditioned-taste aversion after preexposure to flavor (Kalat 1977).

In this study, baits containing microencapsulated LiCl were used to reduce or prevent gustatory and odor cue detection by coyotes. Both experienced sheep killers and naive coyotes (no sheep-killing experience) were tested with LiCl baits to evaluate the effects of specific prey-killing experience. Experiments were conducted to: (1) find the amount of microencapsulated LiCl in sheep baits that produced the strongest bait aversion in coyotes, and (2) test the transfer of bait aversion to sheep-killing aversion in naive and in sheep-killing coyotes. I thank G. E. Connolly, R. T. Sterner, and S. A. Shumake for constructive comments on this paper.

METHODS

The investigation was conducted at the U.S. Fish and Wildlife Service predator research station near Logan, Utah. Coyotes were fed 500 g of commercial animal food/10 kg body weight daily except on days when they ate baits or prey. Coyotes were immobilized with ketamine hydrochloride for weighing. Domestic sheep flesh and hides were used to make treated baits and 8–32-kg lambs were used as the test prey. For bait preparation, sheep killed by coyotes in other experiments were field dressed and skinned. The flesh was ground in an industrial meat grinder, mixed with the appropriate amount of microencapsulated LiCl for each test, and sewed into a fresh piece of sheep hide. Uneaten baits were not offered for more than 3 days, because earlier observations indicated that coyotes began to neck and shoulder rub on baits more than 3 days old. Rubbing is a common canine response to rotten meat and suggests that these baits might have lost their fresh sheep odor.

Experiment 1

Baits were mixed at the rate of 1, 2, 4, or 8 g of microcapsules/500 g of sheep flesh. The microcapsules contained 27% (by weight) of active LiCl. Hence, the LiCl concentrations tested in baits were 0.27, 0.54, 1.08, and 2.16 g/500 g flesh. Three coyotes were used at each treatment level and bait size was adjusted to contain 500 g treated flesh/10 kg of coyote weight when offered. Therefore, the concentrations of LiCl tested on coyotes equaled about 27, 54, 108, and 216 mg/kg. The microcapsules were 420–1,000 μm in diameter and were manufactured by Southwest Research Institute, San Antonio, Texas (mention of manufacturers does not imply endorsement by the U.S. Government). The capsules were coated with beeswax and were designed to pass through the acid pH of the stomach and dissolve in the basic pH of the intestine.

Coyotes were held individually in kennels made of chain link fence that measured $2.4 \times 1.4 \times 1.8$ m high. All coyotes were about 1 year old and had been raised by their natural parents in field pens at our research site.

Before bait testing began, coyotes were fed about 500 g of commercial food daily at about 0800 hours by 1 observer who always drove the same truck. Daily feeding was recorded from the truck parked in the same location each day. All observation periods lasted 4 hours/day. Tests with LiCl-treated baits were conducted similarly and began the day after coyotes ate all the commercial animal food within 10 minutes from the time food was offered on 3 consecutive days. Coyotes were offered 1 treated bait/day (per 4 hours) until a bait was refused (bait aversion). Beginning the day after they showed bait aversion, coyotes were offered 1 untreated bait/day until an untreated bait was con-

sumed (extinction of bait aversion) and thereafter for 3 consecutive days.

Five factors were used to determine which treatment level produced the strongest bait aversion: (1) number of baits eaten, (2) frequency of vomiting, (3) extinction time, (4) time taken by coyotes to consume untreated baits after extinction had occurred, and (5) frequency of leaving bait parts uneaten at the end of the observation period. The LiCl-bait concentration that provided the strongest conditioned bait aversion was used in experiments 2 and 3 to test the transfer of bait aversion to prey-killing aversion.

Experiment 2

The test of transfer of bait aversion to prey-killing aversion in naive coyotes involved a test group of 4 LiCl-baited coyotes and a control group of 4 baited (no LiCl) coyotes. All coyotes were 1–2 years old, and had been raised by their natural parents in field pens in our colony. No coyote from experiment 1 was used. The coyotes were held individually in kennels like those described in experiment 1 and each kennel adjoined a 250-m^2 pen. Coyote movement between the kennels and pens was controlled by a sliding door operated from an observation building above the kennels. Coyotes were observed through a glass window from the building. The observer was screened from the coyotes' view by a sheer curtain. Coyotes were observed individually and each had been allowed several days for pen adjustment before the testing period began.

During the pen-adjustment period, commercial food was placed at varying locations within a pen at 0800 hours each day. An individual coyote was immediately released from its kennel and allowed to feed and roam freely in the pen for the 4-hour observation period. The coyote was then chased back into its kennel and the door was closed. Testing began on the day after a coyote ate all of its commercial animal food within 10 minutes from the time it was offered on 3 consecutive days.

During the testing period, each control-group coyote was allowed to enter the pen and feed on 1 untreated sheep bait each day. On the day after the coyote had eaten 3 untreated baits, a live sheep was placed in the pen and the coyote was released into the pen for 4 hours. Daily pairings of lamb and coyote continued until each coyote had killed and fed on 1 or more lambs, or until 14 days had passed without a lamb kill. During the last 7 days of the 14-day period, if coyotes had not yet killed, they were allowed to stay with the lamb day and night.

During the testing period, each treatment-group coyote was offered 1 LiCl-treated bait/day in the pen until 1 or more baits were eaten, followed by 1 day when bait was refused (bait aversion). On the day following establishment of bait aversion, the coyote was released into the pen that contained a live sheep. Predation tests continued until each coyote had killed and fed on 1 or more lambs, or 14 days had passed without a lamb kill. During the last 7 days of the 14-day period, if coyotes had not yet killed, they were allowed to stay with the lamb day and night. The strength of the transfer from bait aversion to lamb-killing aversion was assessed by comparing the lamb-killing and feeding performance of the treatment and control groups.

Experiment 3

Experiment 3 was conducted like experiment 2, except that no control group was used. Instead, each of the 4 coyotes was allowed to kill and feed on 3 lambs during the 7 days before LiCl baits were

Table 1. Coyote response to 4 treatment levels of microencapsulated LiCl.

LiCl treatment level	Treated baits eaten per coyote	Emesis observed or vomitus found in kennel	Aversion extinction[a] time in days (hours at 4 hours/day)	Feeding time[b] (min)	*N* trials with flesh or hide left uneaten after 4 hours
0.27 g ($N = 2$)	8.0	None	No aversion	No baits offered	
0.54 g ($N = 3$)	9.7	None	No aversion	No baits offered	
1.08 g ($N = 3$)	1.3	None	5.3[c] (21.3)	88.7	7 of 10
2.16 g ($N = 3$)	1.0	2 of 3	2.7[d] (10.7)	29.4	8 of 14

[a] The time between refusal to eat a treated bait and the onset of feeding on untreated baits.
[b] Time coyotes fed on untreated baits after aversion extinction and feeding on untreated baits began.
[c] The 0.54- and 1.08-g treatment levels differed ($P < 0.01$, ANOVA).
[d] The 1.08- and 2.16-g treatments did not differ ($P > 0.05$).

offered. Bait aversion was established as described for experiment 2 and predation tests began the day after a coyote refused to eat treated bait. The strength of the transfer from bait aversion to prey-killing aversion was assessed by comparing the killing and feeding behavior of the coyotes before and after the bait-aversion treatment.

RESULTS

Experiment 1

Of the 4 concentrations of microencapsulated LiCl tested, 1.08 g of LiCl/500 g lamb flesh/10-kg coyote (1.08-g level) produced the most effective bait aversion (Table 1). Coyotes at the 1.08-g level, compared with coyotes at the 2.16-g concentration, (a) showed the bait aversion lasting almost twice as long, (b) took almost 3 times as long to eat untreated baits when feeding on baits resumed, and (c) more often left hide or flesh uneaten at the end of the observation period. Results (b) and (c) indicated that, after extinction, coyotes at the 1.08-g level were most reluctant to consume untreated baits. On the basis of these results, 1.08-g level baits were used to establish bait aversion in experiments 2 and 3.

Experiment 2

The 4 naive coyotes in the control group ate 12 untreated sheep baits (3 baits each). Subsequently, 3 of the coyotes became sheep killers within 2 weeks. The time taken for control coyotes to learn to kill after feeding on the 3rd untreated bait averaged 2.7 days (range 0–7). The 4 coyotes in the test group ate 4.8 baits containing microencapsulated LiCl (1.2 baits each) and showed bait aversion. Subsequently, 3 of the coyotes became sheep killers within 2 weeks. The time taken for the test coyotes to learn to kill, after showing bait aversion, averaged 2.7 days (range 0–7). The test-group coyote that did not kill within 2 weeks (#2) was offered lamb legs with hide and wool intact. The coyote fed on the lamb parts showing no aversion, even though it would not kill sheep. Prey feeding suggested that predation aversion was not the reason that the coyote refused to kill.

The results showed no difference between the control and LiCl-baited groups and thus indicated that the microencapsulated LiCl bait treatment was not effective in reducing coyote predation on sheep. However, 2 of the naive coyotes (1/group) appeared reluctant to attack lambs. Coy-

ote #3 did not kill large (31–32 kg) aggressive lambs, but no reason could be determined for the lack of lamb attack by coyote #2.

Experiment 3

The 4 experienced coyotes ate 4.9 treated baits (1.23 each) and showed bait aversion. Subsequently, all 4 coyotes killed lambs within an average of 0.5 days (range 0–2). One coyote (#3) did not kill an 18.2-kg lamb for 2 days but immediately killed an 8.4-kg lamb on the 3rd day after showing bait aversion. The coyote fed cautiously and then stopped and looked frequently toward the observation building and truck. However, when the the observer drove away and watched through binoculars from nearby, the coyote fed showing no aversion. In subsequent tests the coyote refused to kill the 18.2-kg lamb for 2 more days, but fed on a freshly killed lamb a day later, showing no aversion.

The results indicated that microencapsulated LiCl baits had little or no influence on sheep killing by experienced coyotes. The reactions of coyote #3 suggested that both lamb size and the presence of an observer, his vehicle, or both, might influence killing or feeding behavior of some coyotes (even captive animals accustomed to trucks and people), or that the coyote somehow associated the baits with observers and trucks.

DISCUSSION

Bait Aversion

In an earlier study, Burns and Connolly (1980) tested 3 LiCl concentrations and produced the best jack rabbit bait aversion by using 1 g of LiCl/500 g of jack rabbit flesh/10 kg coyote weight. With microencapsulated (rather than plain) LiCl in sheep baits, coyotes ate and retained (no vomiting) about the same amount (1.08 vs. 1 g) of the LiCl in their systems, but showed the longest average bait aversion (21.3 vs. 16.2 hours of observation) produced under our study conditions. The results indicated that the microencapsulated LiCl was better than plain LiCl and suggested that the reduction in flavor or odor cues (or both) was the reason. The LiCl bait concentrations (about 1 g/500 g) used in these experiments were much lower than those recommended by other investigators, and support suggestions by Griffiths et al. (1978) and Burns (1980) that more attention should be given to LiCl concentrations in baits. The 1.08-g level baits produced the longest bait aversion and this was the highest level at which vomiting did not occur. These results reinforce our previous conclusion that levels of LiCl that do not produce vomiting in coyotes produce the strongest aversion (Burns and Connolly 1980). In general, the strength of aversion is a function of the severity of illness (Garcia et al. 1974). In coyotes, it seems reasonable to suggest that severity of illness is related to the amount of LiCl retained by the coyote and not necessarily to the amount eaten and vomited. The optimum LiCl bait concentration to establish bait aversion in coyotes is probably the largest amount that does not cause emesis. Therefore, anti-emetic drugs might have potential for increasing taste aversion and should be tested in coyotes.

Burns (1980) observed that, after eating LiCl-laced carcasses, coyotes used salt flavor in discriminating between treated carcasses and untreated carcasses or killed prey, and failed to develop prey-killing aversions. Ellins and Martin (1981) demonstrated that coyotes could discriminate between dog food treated at low LiCl concentrations and untreated dog food by olfaction. Their results suggested that coyotes could use LiCl odor as well as taste to discriminate between treated baits and

killed-prey flesh. Logically, they warned researchers and wildlife managers to use proper dosages of LiCl in baits, but they provided no information about what dose might be proper. Gustavson et al. (1982) stated that LiCl sheep baits intended for coyote control should contain at least 100 g of ground sheep and 4 g of LiCl in untreated sheep hide, but they presented no experimental evidence to support the statement. The 4 g of LiCl/100 g flesh appears excessive; coyotes in the Ellins and Martin (1981) study made errorless discrimination between LiCl-treated and untreated dog food patties at this concentration. Also, the 4 g of LiCl/100 g sheep flesh concentration would equal 20 g of LiCl/500 g sheep flesh, whereas results reported by Burns and Connolly (1980) and results from the present study demonstrate that the best LiCl per bait-flesh concentration to produce bait aversion in coyotes is about 1 g of LiCl/500 g prey flesh.

Coyotes in the Ellins and Martin (1981) study made LiCl discrimination errors only 10% of the time at 250 mg/100 g and it appears that most coyotes would also detect LiCl at a 1 g/500 g (200 mg/100 g) concentration in prey flesh. In the present study, microencapsulation of LiCl might have enhanced bait aversion, but it did not prevent predation. However, it might be possible to prevent sheep killing by coyotes by exploiting the ability of coyotes to detect the taste and odor of LiCl. For example, coyotes that learned to avoid LiCl-treated sheep baits might be repelled by sheep that had been sprayed with or dipped in a strong LiCl solution. The repellency would be based on odor and taste cues and could function in the absence of a conditioned predation aversion.

Predation Aversion

Experiments 2 and 3 showed a difference between naive and experienced coyotes in the number of days required before the 1st sheep kill. This difference did not appear to be related to the LiCl bait treatments because killing latency among naive coyotes between the control and test groups was similar. Rather, the difference probably represented the time required for naive coyotes to learn to kill sheep.

Two of the naive coyotes did not kill sheep but this is not unusual and probably cannot be attributed to LiCl influence. Connolly et al. (1976) observed that only 8 of 11 coyotes tested singly with sheep became sheep killers. Also, in other observations at this research site, 3 of 19 pen-raised (naive) coyotes did not kill within 14 days of exposure to lambs (R. E. Griffiths, unpubl. rep., U.S. Dep. Inter., Fish and Wildl. Serv., Denver Wildl. Res. Cent., Denver, Colo., 1978).

It is possible that naive coyote #2 did show conditioned predation aversion for 14 days, or that experienced coyote #3 was prey-averted for the 2 days that it did not kill. The coyotes were probably not prey-averted because the naive coyote fed on sheep parts and the experienced coyote killed and fed on a small lamb. However, these examples indicate that even under carefully controlled experimental conditions, it is difficult to demonstrate bait-induced predation aversion. The extreme difficulty of providing proof of the effect under field conditions has already been pointed out (Griffiths et al. 1978).

In an earlier study at our laboratory, Burns and Connolly (1980) found that naive coyotes pursued and killed jack rabbits shortly after demonstrating LiCl-jack rabbit bait aversion. Jack rabbits always fled when approached closely by the coyotes. In the present study, 1 naive coyote did not kill large aggressive sheep. Connolly et al. (1976) noted that fleeing sheep were always attacked but sheep that did not flee or showed aggressive behavior were not

usually attacked. Thus, it appears that the kind and size of the prey and its behavior can influence attack by coyotes, independently of any LiCl effects, and suggests that care should be taken in interpreting the cause of lack of prey attack after LiCl baiting and in comparing LiCl studies involving different kinds or sizes of prey.

Ellins and Martin (1981:222) observed that feeding coyotes dog food laced with LiCl resulted in "an aversion to cues associated with the higher concentrations of LiCl but no apparent aversion to the cues associated with the plain food." The authors did not clearly indicate that their observation created a question about how well using LiCl baits to produce conditioned predation aversion works on coyotes. They attempted to explain the probable contradiction of their observation with field studies claiming a reduction in killing by coyotes after LiCl baiting, even though none of the studies to date has provided unequivocal evidence that LiCl-sheep baits stop coyote predation on sheep (Bekoff 1975, Griffiths et al. 1978, Sterner and Shumake 1978, Conover et al. 1979). The present study showed that LiCl bait-averted coyotes continued to kill live sheep and feed normally, and supports the earlier suggestion that coyotes can easily discriminate between baits and live prey, and after killing feed because they detect no LiCl. Additionally, Wells and Lehner (1978) reported that coyotes were primarily visual predators. If this is true, bait avoidance based upon taste and odor cues would have little influence on prey killing. Thus, for coyotes to develop prey-aversions it may be necessary to deliver LiCl during the actual killing process and not by baiting.

Burns and Connolly (1980) stated that coyotes can vomit to eliminate ingested poisons and they feed mostly on prey flesh that is usually not poisonous. They suggested, therefore, that coyotes might not have evolved a prey-killing aversion mechanism similar to taste aversion in rats. It is possible, however, that coyotes have the mechanism, but LiCl cannot activate it; i.e., LiCl baits strong enough to cause the transfer from bait aversion to prey-killing aversion can be distinguished from freshly killed prey by taste and odor, and LiCl baits that cannot be separated from prey flesh by taste and odor contain insufficient LiCl to cause the transfer. This latter reasoning suggests that a tasteless, odorless aversive agent in baits might produce a conditioned predation aversion in coyotes.

After an unsuccessful field test using LiCl-sheep baits to stop coyote predation, Bourne and Dorrance (1982) proposed several possible reasons for not showing the effect. One of the reasons was that LiCl baiting may not be effective in suppressing coyote predation on sheep. The present study supports the conclusion of Bourne and Dorrance (1982), by indicating that LiCl-sheep baits produce no predation aversion to sheep in coyotes.

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