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ABSTRACT: Theoretical concepts from foraging ecology were studied to identify elements of blackbird foraging strategies that may be manipulated to deter blackbirds feeding on rice. Seed-handling time was identified as one such vulnerable element. Consequently, we developed seed coatings for rice that increased handling time per seed, allowed a satisfactory germination rate, and persisted for several days postplanting. Test coats included hydrophilic binders with several starches, clays, plaster of paris and chemical grout in various combinations. Consistent repellency was achieved in feeding trials with captive red-winged blackbirds.

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## INTRODUCTION

Many wildlife depredation problems are readily explained by foraging ecology theory (Krebs et al. 1983, Kamil et al. 1987). In almost every agricultural situation, conditions are such that animals should forage frequently, preferentially, and intensively. Large homogenous patches of grains, fruits, and livestock distributed extensively throughout wildlife habitats have greatly increased food availability. Concurrent reduction or elimination of competitors, predators, and alternate foods have simplified foraging conflicts for many species. Selective breeding of plants and livestock has improved the nutritional quality of food for wildlife. In many instances mankind has even provided this bounty during critical periods of many species' life cycles. Therefore, it is not surprising that many species that survived the transition from the primal to the pan-agricultural environment have flourished and now compete seriously with human interests.

Realizing that many, if not all, depredation problems are a predictable result of the enhanced foraging environment, we evaluated various aspects of that environment, in light of foraging ecology theory, to determine what manipulations might reduce or eliminate depredations. Decreasing the value of the prey item to the bird or increasing the bird's uncertainty in correctly identifying suitable prey items are key theoretical concepts underlying recent research on aversive conditioning (Mason et al. 1984), repellents (Mason et al. 1985), applied mimicry theory (Avery 1985), and toxic baiting (Glahn et al. 1986).

Another component of foraging behavior, handling time or search time per prey item (hereafter referred to as interprey interval, IPI), can be manipulated to help reduce bird depredations to crops. We hypothesize that as IPI increases beyond some undetermined threshold, birds should reject the prey item (Palmer 1981). After repeated encounters with such prey items, a bird's net rate of energy intake will decline to the point where it no longer profits the bird to remain at that site. Then the bird will abandon the patch and forage elsewhere (Charnov 1976).

Although our results may have additional application, we have concentrated on rice seed depredation by red-winged blackbirds (Agelaius phoeniceus). This is a particularly serious problem in parts of southwestern Louisiana where rice seed is aerially sown over flooded fields. After sowing, the water may be drawn off the fields immediately, or the seed may remain submerged for several days to protect against freezing. When the water level is lowered, the seeds germinate and are exposed to depredation by blackbirds for several days. Our objectives were:

1) to develop a seed coating that would increase handling time such that the birds would reject the seed,
2) to compose the coating of environmentally innocuous materials,
3) to assure that the coating process was feasible within the agriculture community, and
4) to determine the efficacy of the seed coating under a 2-choice test.

## METHODS

### Seed Coat Development

In addition to the constraints imposed by Objectives 2 and 3, it was also essential that any seed coating be retained during prolonged immersion in water, hydrophilic, nonphytotoxic, and plantable (i.e., the seed should be dry and flowable prior to planting and the coating tough enough to withstand handling). Our approach was to identify substances that would adhere to the seeds and dry to reasonably hard coats, but become sticky or gummy when wetted. After numerous rejections (primarily starches and adhesives), we determined that a clay coating was the most feasible option. Although several clay seed coatings have been patented (Dannelly 1981, Katamura and Watanabe 1981, Matsunage et al. 1981), each was designed to disintegrate when wetted. We required a coating that would be retained until the seed germ had been utilized. Seed coat retention after immersion in standing water for up to 2 wk was attained by blending western bentonite and KT1-4 ball clay in ratios between 40:60 and 60:40 bentonite to ball clay. It was also necessary to overcoat with a spreader-sticker (e.g., latex, grout extenders, or Rhoplex™) or to integrate gelatine (Knox Gelatine Inc, Englewood Cliffs, NJ 07632) or Scotch-Seal™ Chemical Grout 5600 (3M Company, St. Paul, MN 55144-1000) as binding agents.

In preliminary trials, some seed coat erosion occurred when the seeds were impacted by rain drops. Improved protection from erosion was achieved by both integrating the binder solution and overcoating with a mix of gelatine and a commercial spreader-sticker.

We tested numerous coatings, but only those deemed most feasible are discussed here. Although varying slightly in the coating process, coatings with repellency potential fell into 3 groups: starches, clay coating with a binder overcoat, or clay with an integrated binder.

One-Choice Screening Tests

As seed coats were developed they were subjected to screening tests which followed the methods of Schafer and Brunton (1971). Ten individually caged adult male red-winged blackbirds were each offered 25 untreated rice seeds for 18 h. Birds that ate all 25 seeds were then offered 25 coated seeds, activated by presoaking in tap water, for an additional 18 h. Successful tests were verified by 1 additional application. A coating was considered repellent when <50% of the birds took <50% of the treated seeds during each of the 18-h test period.

Behavior Observations

Two series of behavior observations were conducted using adult male redwings exposed to the seed coating that was most repellent during the screening tests (clay with integrated binder). The first demonstrated qualitatively how the birds reacted to the treated seed and the second quantified feeding rates.

In the first series, solitary birds were placed in a 50 x 30 x 30-cm aquarium with 5 coated seeds activated by presoaking. The birds were observed remotely for 5 min via closed-circuit television and notes were taken on their activities. Subsequently, those birds were presented with 5 untreated seeds and observations were repeated.

The second series entailed confining 8 male redwings in individual outdoor cages (1.8 x 1.2 x 1.2 m). Food was withheld overnight, but water was provided ad libitum. Pairs of birds were observed simultaneously with one offered 5 treated seeds and the other 5 untreated seeds. The time to first peck and the time to eat each seed were recorded. After logarithmic transformation of the data, paired t-tests were performed on latency to first peck and the interval between seeds eaten. If either bird failed to eat all 5 seeds in 10 min, the seeds were left in the cage and spot checked at 30-min intervals until at least 4 seeds were taken or 3.5 h had elapsed. Notes were also taken on the number of seeds pecked but not eaten.

Two-Choice Enclosure Test

Efficacy tests with alternate prey available were conducted in an outdoor enclosure (9.1 x 3.0 x 2.4 m). Perches, shade, and water were provided. The enclosure floor was tilled, weeded, smoothed and divided lengthwise into 2 plots, each 9.1 x 1.2 m. The soil was watered with a garden sprinkler until saturated. One plot was then hand sown with untreated seed at the rate of 132 kg/ha, and the other plot received an equivalent amount of treated seed. The amount of treated seed, which was heavier than untreated seed due to the seed coating, was determined by counting 5 samples of the prescribed amount (147 g) of untreated seeds. The mean number of seeds/sample (5,662 + 18 s.d.) was determined with a seed counter and each plot was planted with the same number of seeds.

Four naive adult male redwings, which had been cage acclimated for at least 1 month, were allowed to forage within the enclosure for 3 days. Assuming each bird consumed 12.4 g of rice/day (Meanley 1971), they should have eaten about half of the available seeds within 3 days. Each bird was uniquely banded and was weighed before and after each experiment. The experimental seed coats were activated by the soil moisture, and periodic watering maintained a high moisture content. After the 3-day exposure period, the birds were removed and the seeds were counted in from 19 to 30 pairs of 0.09 $m^2$ quadrats along the length of the mid-line of each plot. For each coating, paired t-tests were performed on the mean number of seeds remaining in treated and untreated plots.

Germination Tests

Germination success was assessed for the most promising clay formulations by 2 methods. The first involved immersing 5 treated and 5 untreated seeds in the same water-filled petri dish. Ten replications were conducted for each of 3 formulations. The number germinated after 7 days was recorded, and differences in germination rate were analyzed with paired-sample t-tests. The second test involved planting 100 coated and 100 uncoated seeds through a template into saturated potting soil. The date of first emergence, the number emerged daily for 7 days after first emergence, and the length of 20 randomly selected shoots at days 3 and 10 postemergence were determined. Six replications were conducted and germination rates were analyzed with paired-sample t-tests.

## RESULTS

Seed Coat Formulations

Due to high cost or technical difficulties, only variations of the clay coating and a few commercial starches showed promise as bird repellents. The starch coatings were extremely tacky when slightly damp. Natural moisture on a fingertip was adequate to glue the seed and vigorous shaking would not dislodge it. However, when thoroughly wetted, the starches swelled and became slick, gelatinous, and translucent. In that state the coatings were easily washed or wiped off. Starch coatings were also disadvantageous because ambient humidity caused the seeds to aggregate unless stored in a perfectly dry environment. Although poor when wet, starch coatings may be useful under moderately dry seed bed conditions.

Two variations of a clay coating proved feasible under wet conditions. The simplest involved tumbling seed wetted with tap water through dry clay to build a shell. The coated seed was then overcoated with a commercial spreader-sticker to help hold the overcoat together when saturated. Another variation was similar except that gelatine was dissolved in the tap water prior to wetting the seed. It acted as an integrated binder to hold the coating together when saturated.

When immersed in water the clay coatings swelled and became slick and sticky. This texture was retained for up to 2 wk when left immersed in standing water. They also retained a gummy texture for hours or days (depending on temperature) after the water was removed. Wet clay-coated seeds were difficult to pick up, and when plucked or pecked left a slick gummy smear on the fingers or beak. They also stored well. Clay-coated seed had one additional characteristic. When sown over wet soil they aggregated soil particles and debris which provided camouflage.

One-Choice Screening Tests

Starch-based formulations failed the screening tests with only 1 of 15 birds not eating at least half of the seeds (Table 1). Both clay formulations passed the test, and for the coating with the integrated binder, no bird took 50% of the seeds (maximum consumption was 5 of 25 seeds in 18 h). Although the clay coating with a binder overcoat passed the screening, 30% of the birds ate over half of the seeds, and 1 bird ate them all.

Table 1. Screening results for 3 seed coatings showing the number of birds consuming less than half of the 25 seeds available.

| Formulation type | No. of birds | No. of birds taking < 50% |
|---|---|---|
| Starch | 15 | 1 |
| Clay with binder overcoat | 18 | 12 |
| Clay with integrated binder | 16 | 16 |
| Control | 49 | 0 |

Behavior Observations

There was little qualitative difference in birds' reactions to seeds with different seed coatings. There was a tendency to peck seeds with a starch coating sooner than those with clay coats. Starch coatings were transparent and revealed the seed immediately whereas clay-coated seeds were hidden in a mud shell. When confronted with coated seeds, a bird typically 1) approached the seed tray and scanned the contents several times before pecking; 2) pecked a seed; 3) flitted about the aquarium and wiped his beak; and 4) often repeated steps 2 and 3. Some birds threw the coated seeds. No bird ate a coated seed during the 5-min observation period. In contrast, when the same birds were presented with uncoated seeds, they usually began eating immediately after the first peck and consumed all of the seeds within 5 min.

Differences in behavior patterns were quantified by the paired observations of birds presented with coated seeds (Table 2). Latency to first peck ($0.1>P>0.05$)and interval between seeds ($0.05>P>0.02$) were greater with coated than with uncoated seeds. A portion of the IPI of the treated birds was devoted to grooming the seed coating from their beaks. Although 1 bird sampled the coated seeds at the same time as did the control, the IPI was almost 3 times that of the control. That replication was exceptional because the control bird appeared nervous and showed little interest in his food tray. The other control birds ate all 5 of their seeds without hesitation. During the other replications 1 experimental bird showed no interest in the treated seed (although he repeatedly investigated his food tray) and the others took at least 40 times longer than control birds to begin pecking. The IPI of experimental birds that repeatedly pecked treated seeds was up to 7 times that of control birds. After the coatings became dry and crusty, one experimental bird ate 5 treated seeds and another ate 4.

Two-Choice Enclosure Tests

With each coating, seed loss in the untreated plot was 4-5 times that in the treated plot (Table 3). On one occasion nearly all seeds were removed from the untreated plot while only a third was missing from the treated, and in two instances seed loss from the treated plots was undetectable. Although the treatments seemed effective, the limited number of replications precluded demonstration of statistically significant differences (for each coating $0.2>P>0.1$). Weight loss/bird averaged 6-9% over all the trials, so we assume there was adequate incentive to consume any seed the birds could eat.

Germination

No differences were found in final seed germination regardless of seed coating (Table 4). There was a slight delay in sprouting of clay-coated seeds (Fig. 1), but coated seed batches always caught up to uncoated seed by the seventh day postplanting (about 3 days postemergence). Coated seeds in our experiments had a faster initial growth rate than uncoated seeds and were slightly taller by the third day postemergence. This result may be because the

Table 2. Behavior patterns of paired adult male redwings offered either clay-coated seeds (TRT) or uncoated seeds (UNT).

| Rep. | Latency to 1st peck (sec) | | Mean interseed interval (sec) | | Seeds eaten | | Elapsd time (h) | |
|---|---|---|---|---|---|---|---|---|
| | TRT | UNT | TRT | UNT | TRT | UNT | TRT | UNT |
| I | 497 | 10 | 600[a] | 14.5 | 1 | 5 | 3.5 | 0.02 |
| II | 40 | 1 | 135[b] | 17.25 | 5 | 5 | 2.0 | 0.02 |
| III | 600[a] | 6 | 600[a] | 11.25 | 4 | 5 | 2.0 | 0.02 |
| IV | 6 | 6 | 314[b] | 130 | 2 | 4 | 2.0 | 2.0 |
| x̄ | 285.7 | 5.8 | 412.3 | 73.1 | 3 | 4.8 | 2.4 | 0.5 |

[a]No seed pecked or eaten during the 10-min observation period. For statistical analysis, the maximum value of 600 sec was used.
[b]Only 1 seed was eaten but a second was pecked.

Table 3. Mean (+ s.d.) seed loss during 2-choice enclosure tests using 4 adult male redwings presented with equal-sized plots containing clay-coated (TRT) seeds and uncoated seeds (UNT). The initial seed density was 47 seeds/0.09 $m^2$ quadrat.

| Replicate | Pairs of subplots | Final seed density (% loss) | |
|---|---|---|---|
| | | TRT | UNT |
| I[a] | 19 | 31 ± 20 (34%) | 0.4 ± 1 (99%) |
| II[a] | 19 | 55 ± 22 ( 0%) | 12 ± 11 (74%) |
| III[a] | 28 | 63 ± 19 ( 0%) | 8 ± 14 (83%) |
| IV[b] | 30 | 39 ± 18 (17%) | 20 ± 15 (57%) |
| V[b] | 27 | 29 ± 16 (38%) | 6 ± 10 (87%) |

[a] Clay-coated seed with integrated binder but no overcoat.
[b] Clay-coated seed with integrated binder and a binder overcoat.

Table 4. Comparison of the number of clay-coated (TRT) seeds to uncoated (UNT) seeds that germinated after 7 days. Two coating techniques (with and without a binder over-coat) and 2 planting mediums were employed.

| Treatment | Medium | Number of Seeds | Number of Replicates | x̄ % germination TRT | x̄ % germination UNT | P |
|---|---|---|---|---|---|---|
| Uncoated vs. clay w/o binder overcoat | water | 5 ea | 10 | 46 | 60 | >0.5 |
| Uncoated vs. clay with binder overcoat | water | 5 ea | 10 | 52 | 50 | >0.9 |
| Clay coat with binder overcoat vs. without binder overcoat | water | 5 ea | 10 | 46[a] | 52[b] | >0.5 |
| Uncoated vs. clay with binder overcoat | soil | 100 ea | 6 | 88 | 87 | >0.1 |

a Without binder
b With binder

clay coatings held moisture immediately adjacent to the seed better than the potting soil medium alone.

DISCUSSION

Originally, our intent was to find a gummy substance (e.g. rubber cement) that could be applied to seeds such that birds would foul their beaks and be forced to groom between each seed. Theory, as well as reason, dictates that a bird faced with the resulting long IPI should promptly abandon such a foraging patch (Dolbeer et al. 1982). Although we have yet to find a compound that fully meets our expectations, the clay coatings are close and appear to be quite functional.

Although we attempted to develop a tactile aversive, it can be argued that we have simply devised a way to hide the seeds from view. The clay coatings disguise the seed and they also aggregate soil and detritus producing additional camouflage. They are very difficult for humans to

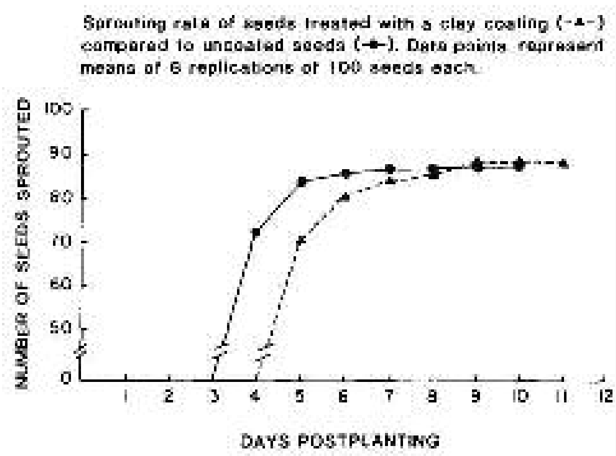


Fig. 1. Results of sprouting studies of seeds.

count when sown on experimental plots. Although imparting some hiding effect, the coatings were aversive even when presented in an obvious manner (Table 2).

The results from our 2-choice enclosure test demonstrate that blackbirds will eat the clay-coated seeds (up to 38%, Table 3) even when some uncoated seeds are available. However, in every replication each bird lost weight despite the fact that there were numerous coated seeds present. We suspect that as the preferred uncoated seeds were depleted they became more difficult to find and search time increased. It is reasonable that by the third day the increase in search time on the untreated plot offset the effects of prolonged handling time presented by the treated seeds. The availability of alternate prey is a critical component of all theories relating to food patch abandonment due to prolonged IPI and any successful repellent probably requires the presence of alternate prey.

There was also some erosion of the clay coats due to raindrops. Possibly, the seeds missing from the treated plots had lost their protective coating during rainstorms. The erosion problem prompted us to explore protective binder overcoats for the clay coatings. Coat retention improved in the overcoated seeds and there was no effect on either germination or repellency. However, overcoating did increase the cost of the treatment.

Our coatings employed approximately equal weights of clay and seed. Although clay is inexpensive, it is very heavy. Thus, much of the cost of our coatings was due to freight charges for the clay. Our costs per cwt seed (excluding seed costs) came to over S90.00. However, we purchased our components prepackaged and retail. We also used high-grade gelatine (suitable for human consumption) which would probably not be essential for field use. Costs for bulk processing arc currently uncertain, and we have not conducted an exhaustive fiscal analysis which would include the increased costs of aerial seeding due to greater seed weight, as well as the anticipated savings expected from coated seeds. Farmers in south Louisiana currently overplant up to 100% (pers. obs.) to assure adequate seed survival in the face of severe bird depredations. A 50% reduction in seed loss would offset much of the seed coating expense. Also, clay is inert so that a variety of fertilizers, insecticides, hormones, etc., could be incorporated into the seed coat, which would reduce operating costs by performing many operations at once.

Although we have not perfected our seed coating, we believe that this alternative approach to bird repellents is sound. We encourage a continued search for suitable tactile aversives and recommend field testing of these clay coats.

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