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### Authors

Bogardus, Tyler  
Joe, Stephanie M.  
Shiels, Aaron B.

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# Development of a Rodent Bait with Slug-repellent Properties

Tyler Bogardus and Stephanie M. Joe

University of Hawaii, Office of the Vice President for Research and Innovation, in support of the Army Natural Resources Program on Oahu, Schofield Barracks, Hawaii

Aaron B. Shiels

USDA APHIS, Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado

**ABSTRACT:** Since 1995, the Army's Natural Resources Program on O'ahu has been controlling rodents in O'ahu's forests to protect native plants, invertebrates, and birds. Bait longevity and attractiveness are keys to successful rodent trapping. Success is impeded when slugs interfere with bait intended for rodents. Slugs can consume all or a portion of the bait, make it less attractive to rodents via their slime, and large slugs can trigger the traps. The goal of this study was to determine whether food grade citric acid (up to 5% concentration) added to common rodent bait (i.e., commercial peanut butter and Goodnature lure) would repel slugs. We conducted several trials including where captive slugs were offered both a test (0.5-5% citric acid added) and control bait. We found slugs significantly preferred the control bait (i.e., bait without any citric acid) in the two-choice feeding experiment when the bait was Goodnature rat + mouse lure. Goodnature rat + mouse lure is the standard bait used in A24 self-resetting rat traps. The addition of citric acid may improve the longevity and attractiveness of bait to rodents in slug-inhabited environments, thereby having the potential to aid in rodent control programs.

**KEY WORDS:** bait deterrent, citric acid, island invasive pest species, non-target species, rodent management, trap repellent

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## INTRODUCTION

A common problem experienced during rodent pest control occurs from bait loss or contamination by nontarget species, especially invertebrates such as slugs (Anderson and Ohmart 1977). Slugs can consume bait or make it less attractive to rodents via slime deposits, and large slugs can trigger traps. Once slugs spoil or consume rodent bait, the rodent control device becomes ineffective for attracting and euthanizing rodents, which is inefficient for long-term rodent control programs. Therefore, development of a slug deterrent that could be added to standard food-based baits may be an efficient solution to rodent pest control.

Introduced rats are a major threat to natural resources in mesic forests on the island of Oahu (Meyer and Shiels 2009), and non-native slugs are also abundant in these forests (Joe and Daehler 2008). In many of these forests, the U.S. Army's Natural Resources Program (ANRP) has been engaged in rodent control since 1995 using various techniques including snap traps, automatic traps, diphacinone rodenticide applied in bait stations, and physical barriers. Grids of Goodnature A24 rat + stoat traps (Goodnature Limited, Wellington, NZ; hereafter A24 traps or A24s) are now used to protect native species from rats at most ANRP management units. A24s are self-resetting traps that can fire 24 times with one CO<sub>2</sub> cartridge (Carter et al. 2016, Shiels et al. 2019), and with automated lure pumps they typically do not require servicing (i.e., re-baiting and changing CO<sub>2</sub> cartridges) for about 4 months (Bogardus and Shiels 2020). A24s have been shown to successfully control rat populations in ANRP management units and mesic forests (Shiels et al. 2019), but there is room for improved efficiency because slugs commonly spoil the bait within the first 1-3 nights following arming and baiting the traps. Because previous efforts by ANRP to reduce or eliminate bait contamination and consumption

by slugs have been largely unsuccessful (Kawelo et al. 2012), the food additive citric acid was pursued. Citric acid is a common flavoring agent, preservative, and acidifier; it occurs naturally in citrus fruit in concentrations as high as 8% by weight. We know of no formal studies that have trialed citric acid as a deterrent against slugs.

Our goal for the current study was to determine whether food grade citric acid added to rodent bait would repel slugs. We conducted several trials with captive slugs using three types of bait (Skipppy<sup>®</sup> Peanut Butter [Hormel Foods LLC, Austin, MN], Goodnature Peanut Butter, and Goodnature Chocolate; the latter is used in A24 traps) with and without 0.5-5% citric acid added to the baits. Although we also performed laboratory and field trials examining rodent responses to baits with or without citric acid, the results of those trials will be reported outside of this manuscript.

## METHODS

Two sets of laboratory trials tested if slugs are deterred by 0.5-5% citric acid when added to various rodent baits/lures. In the first trial (a two-choice trial), 50 slugs were collected from Waianae Mountains in Oahu during the month of March 2016. The dominant slug species were *Deroceras laeve* (n = 28; mean weight ± SD: 0.30 ± 0.16 g) and *Limax maximus* (n = 18; mean weight ± SD: 3.20 ± 2.43 g). The slugs were kept moist and fed lettuce, carrots and Beneful brand dog food (Purina, Société des Produits Nestlé S.A., Vevey, Switzerland) until the start of the trial on April 19<sup>th</sup>. Slugs were not starved prior to this experiment. The trial ended two weeks later on May 3<sup>rd</sup>. During this period slugs were kept in individual plastic containers and offered 2 g of the test bait (5% citric acid added to Goodnature Peanut Butter Lure) and 2 g of the control bait (no citric acid added to Goodnature Peanut Butter Lure), dyed with red and green food coloring



**Figure 1. Photographs of the slugs *Deroceras laeve* (left) and *Limax maximus* (right) in treatment containers showing the bait arrangement and container types. The *D. laeve* was in small (3 oz.) cups, and trials were discontinued because an insufficient number of slugs could be obtained, while the *L. maximus* was in the larger (8 oz.) cups and were successfully used in the majority of our trials.**

respectively. Small slugs (<3 g in weight) were housed in 3-ounce cups 7 cm in diameter while larger ones (>3 g) were placed in 8-ounce cups 11 cm in diameter (Figure 1). Every 48 hours, each slug and their baits were weighed, cages cleaned of feces, and observations made on the condition of the bait such as whether any evidence of feeding occurred (radula marks) or whether mold was present.

In the second trial (also a two-choice trial), only one species of slug was used (*Limax maximus*) because insufficient numbers of the other species (*D. laeve*) were obtained. Testing took place on different dates (February-April 2017) and with a different group of slugs in each trial. No slugs were used in more than one study, and each trial lasted for 14 days. Any slugs that died during this time or did not consume any bait in their cage (i.e., test or control bait) for multiple continuous days were not used in our results or subsequent statistical analysis as their health was potentially comprised by illness or some unknown factor causing them to behave abnormally. Each of the five trials were two-choice trials where the test bait (with citric acid added) was offered simultaneously with the control bait (no citric acid added) in the same container. The five trials were: 1) Goodnature Chocolate Lure with 0.5% citric acid added in the test bait (n = 16); 2) Goodnature Chocolate Lure with 5% citric acid added in the test bait (n = 11); 3) Goodnature Chocolate Lure with 3% citric acid added in the test bait (n = 11); 4) Goodnature Chocolate Lure with 2% citric acid added in the test bait (n = 10); and 5) Skippy

Creamy Peanut Butter with 5% citric acid added in the test bait (n = 13). Slugs were kept in 32-ounce plastic containers, and offered 2 g of the test and 2 g of the control bait in marked petri dishes, to prevent confusion between the two baits. Every 48 hours, each slug and their baits were weighed, cages cleaned of feces, and observations made on the condition of the bait.

Laboratory trial data were analyzed using Minitab 14 software (Minitab Inc., State College, PA). A two-sample t-test was used to compare each treatment against its control group at the end of the study. Data that were used in analyses were the changes in bait-weight of each treatment and its control group divided by the weight of the slug.

## RESULTS

At the conclusion of the laboratory feeding trials with slugs, all test baits were significantly avoided by slugs over their control except for two: 0.5% CA in Goodnature Chocolate Lure (P = 0.369) and 5% Skippy Peanut Butter (P = 0.328) (Table 1). All other test baits showed significantly less feeding by slugs when compared to feeding on the control baits (Table 1). Therefore, citric acid as an additive to rodent bait deterred slugs from feeding, at least when added at 2-5% concentration to Goodnature Chocolate Lure, or when 5% is added to Goodnature Peanut Butter Lure.

**Table 1. Summary results from 2-choice laboratory feeding trials to determine if *Limax maximus* slugs are deterred by adding citric acid into three types of rodent bait/lure. All trials last 14 days and occurred in 2016-2017 in Wahiawa, Hawaii. Sample sizes were n = 9-16 per treatment.**

Lure/Bait	Concentration of Citric Acid	Statistics: t-test, df, P-value	Outcome: Were Slugs Deterred by Citric Acid?
Goodnature Peanut Butter Lure	5%	t = 4.03, df = 20, P < 0.001	Yes
Goodnature Chocolate Lure	0.5%	t = 0.91, df = 28, P = 0.369	No
Goodnature Chocolate Lure	2%	t = 2.09, df = 17, P = 0.050	No
Goodnature Chocolate Lure	3%	t = 6.42, df = 15, P < 0.001	Yes
Goodnature Chocolate Lure	5%	t = 6.80, df = 14, P < 0.001	Yes
Skippy Peanut Butter	5%	t = 1.00, df = 23, P = 0.328	No

## DISCUSSION

Citric acid, particularly when added to Goodnature Chocolate Lure in concentrations of 2-5%, appears to be an effective slug deterrent. Such a finding shows promise for improving rodent pest control in humid environments worldwide where slugs recruit to, and spoil, rodent baits in traps. Reductions in slug interference during rodent control may increase trap efficiency by increasing bait longevity.

It is unclear why Skippy Peanut Butter did not show significant slug deterrence, but Goodnature Peanut Butter did show significant slug deterrence, when combined with 5% citric acid. One possibility is that the relatively high salt and sugar contents of the Skippy Peanut Butter may interact or interfere with the citric acid, thereby nullifying the slug deterrent effect, at least at the 5% additive concentration of citric acid. Although the ingredient list for Goodnature Peanut Butter Lure is unavailable, it appears to be less salty and sweet than Skippy Peanut Butter. Future trials with >5% citric acid mixed into Skippy Peanut Butter are needed, as well as additional trials with other commonly available commercial brands of peanut butter.

The extended bait longevity and effectiveness due to adding 5% citric acid to Goodnature lure is particularly favorable for ANRP's use of A24 traps. One of the early concerns about the A24 traps was that the bait was not as attractive to rats over extended periods (Gillies et al. 2012). However, with 5% citric acid added, we anticipate the need to service traps (replacing the ALP with a new one) will be extended an additional two months (i.e., from Goodnature's recommended four months to our finding of it lasting about six months; Bogardus and Shiels 2020). Even though the A24s have been shown to be effective at suppressing invasive rats in New Zealand (Carter et al. 2016) and Hawaii (Shiels et al. 2019) when citric acid was not added to the bait/lure, we now predict longer efficacy of the traps if 5% citric acid was to be added to the bait.

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