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LABORATORY EVALUATION OF PREDATOR ODORS FOR ELICITING AN AVOIDANCE RESPONSE IN ROOF RATS (*Rattus rattus*)

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Abstract—We evaluated eight synthetic predator odors and mongoose (*Herpestes auro-punctatus*) feces for eliciting avoidance responses and/or reduced feeding by wild captured Hawaiian roof rats (*Rattus rattus*). In a bioassay arena, we recorded: (1) time until each rat entered the arena, (2) time elapsed until first eating bout, (3) time spent in each half of the arena, (4) number of eating bouts, and (5) consumption. Rats displayed a response to the predator odors in terms of increased elapsed time before initial arena entry and initial eating bout, a lower number of eating bouts, and less food consumption than in the respective control groups. The odor that produced the greatest differences in response relative to the control group was 3,3-dimethyl-1,2-dithiolane [from red fox (*Vulpes vulpes*) feces and mustelid anal scent gland]. Mongoose fecal odor produced different responses in four of the five variables measured while (*E,Z*)-2,4,5-trimethyl- Δ^3 -thiazoline (red fox feces) and 4-mercapto-4-methylpentan-2-one (red fox urine and feces) odors were different from the control group in three of the five variables measured. These laboratory responses suggest that wild Hawaiian roof rats avoid predator odors.

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Key Words—Laboratory bioassay, *Rattus rattus*, roof rats, avoidance behavior, mustelids, anal-gland compounds, red fox urine, feces, *Vulpes vulpes*, mongoose, *Herpestes auropunctatus*.

INTRODUCTION

The macadamia nut (*Macadamia integrifolia*) is a desirable food item internationally and is a crop of high commercial value. Crop damage by rodents has been a problem on the Hawaiian Islands for many years, and annual losses have been estimated at \$3–4 million (Tobin et al., 1993). The roof rat (*Rattus rattus*) has been identified as the primary pest species in macadamia nut orchards, with the Polynesian rat (*R. exulans*) also present, but not considered as a serious damage agent (Tobin, 1992). Various management techniques have been applied, but none has proven effective.

Current rodent control techniques in Hawaii involve poisoning (rodenticides) and/or the use of kill-traps. Studies on the effectiveness of common rodenticides have shown many poisons to be too selective for certain rat species (Tobin, 1992). This selectiveness is related to increased zinc phosphide use and is believed to explain the increase in Norway rat (*Rattus norvegicus*) populations relative to the roof and Polynesian rat (*Rattus exulans*) in sugarcane fields (Tobin et al., 1990). Another basic problem with zinc phosphide is bait shyness resulting from sublethal consumption of the bait. As macadamia growers need to protect their crop over an extended period of time, this learned bait avoidance becomes a problem. Timing of application in the orchard is important, and restrictions regarding the use of zinc phosphide prior to harvest are currently required, primarily to reduce crop residues and primary/secondary accidental poisoning of humans. The potential effects on other nontarget animals (e.g., feral pigs, avian predators) and possible transmission through the food web are also of concern with anticoagulant rodenticides (Engeman and Pank, 1984).

The use of synthetic predator semiochemicals in wildlife management is a growing area of research. Although pheromones have been used extensively in agricultural pest management, the focus has been primarily on invertebrate communities. The application of predator odors as a management tool at the small mammal level has been recently investigated. Sullivan et al. (1988a–c) have shown suppressed damage and/or an avoidance response in synthetic predator odor experiments with various small mammal populations in both agricultural and forested ecosystems. Significant results have been observed in the following North American species: an avoidance response in snowshoe hare (*Lepus americanus*) in coniferous seedling plantations, suppressed feeding by montane and meadow voles (*Microtus montanus* and *M. pennsylvanicus*) in apple tree orchards, and an avoidance response by northern pocket gophers (*Thomomys talpoides*) in apple tree orchards.

The encouraging results from the previously described odor response studies, combined with an extensive rodent problem on the Hawaiian Islands, provided an ideal situation in which to explore potential management applications. A recent field study in Hawaii also indicated that rats avoid traps scented with mongoose feces (*Herpestes auro punctatus*) (Tobin et al., 1995). We examined the possibility of using synthetic predator odors to prevent feeding damage by rats in a macadamia nut orchard. This biological control method attempts to prevent rodent damage through a behavioral response to a predator odor. Although most of the odors tested were not those of established predators on the Hawaiian Islands, we predicted that a fear/avoidance response should be innate. Volatiles from red fox (*Vulpes vulpes*) fecal droppings elicited a fear response in Wistar lab rats that had not been in contact with predators for generations (Vernet-Maury et al., 1984). Boag and Mlotkiewicz (1994) found decreased rabbit numbers in areas treated with a complex multicomponent synthetic repellent derived from lion feces. Self-anointing behavior with weasel (*Mustela sibirica*) anal scent gland secretion, considered a defensive response, was displayed by juvenile rice-field rats (*Rattus rattoides*) that had been lab reared (Xu et al. 1995).

We based our predictions of roof rat response to predator odors on previous studies involving other small mammal species. Vernet-Maury et al. (1992) assessed fear response observations of wild-caught Norway rats (*Rattus norvegicus*) in an open-field arena, measuring time of emergence, exploratory movements, grooming, urination, and defecation. Other studies found reduced food consumption by small mammals in response to predator odors (Calder and Gorman, 1991; Eppe et al., 1993; Heale and Vanderwolf, 1994). Based on the success of these various studies and the apparent innate responses by small herbivores to carnivore odors, we predict that roof rat behavior can be manipulated with synthetic odors in the laboratory.

This study was designed to test the hypotheses that presence of a predator odor will: (1) increase the time elapsed before an individual first enters the arena and before its first eating bout for the treatment groups relative to the control group; (2) reduce the amount of time spent on the treated side relative to the control side and reduce the total time spent on both sides of the arena; (3) reduce the number of eating bouts on the treated side relative to the control side; and (4) reduce the amount of food consumed on the treated side relative to the control side.

METHODS AND MATERIALS

An open-box arena design allowed a large viewing area to observe an individual rat's response. A video camera (JVC BY-1000) situated above the

arena recorded the information and eliminated observer bias. As a plantation management interest was to reduce feeding damage, consumption became one of the response variables measured. Other quantitative variables measured were time to first entry, time to first eating bout, time spent in arena, and number of eating bouts. Separating the open box arena into two identical halves allowed a predator odor to be tested against a control.

Capture and Maintenance of Animals. Roof rats were live-trapped in the Waikaea Forest Reserve on the island of Hawaii and maintained in animal rooms at the United States Department of Agriculture (USDA)/Animal and Plant Health Inspection Service (APHIS)/Animal Damage Control (ADC)/Denver Wildlife Research Center (DWRC) field station in Hilo. Only adult animals (sexually mature and weight ≥ 90 g) were maintained for testing. Over 120 roof rats were initially captured, from which 100 animals (50 of each sex) were randomly selected to meet the study design requirements of 100 animals. Test animals were housed in individually numbered cages and were provided with water and laboratory chow *ad libitum* prior to testing. The animals were maintained on a 12L:12D schedule with the room temperature ranging from 20° to 22°C.

Mongoose, maintained to collect fresh fecal samples, were captured in gulch regions near the city of Hilo and were also housed at the DWRC Hilo Field Station. Two adult mongooses, one of each sex, were maintained in an outdoor wire pen and provided with shelter, bedding, water *ad libitum*, and fed one rat per day.

Assignment to Treatment Groups. The 100 test rats were assigned to 10 treatment groups using a randomization program that ranked each sex group by weight before randomly assigning treatments. Following the treatment assignment, each test group consisted of five males and five females. As the odor trials were divided into two phases, each treatment group was further divided into two subgroups (two males/three females or three males/two females). The test animals were then housed according to treatment group and subgroup (A or B).

Arena Design. The size of the arena was maximized according to the largest field of view allowable with the video camera lens. The arena measured 150 cm long \times 60 cm wide \times 120 cm high (Figure 1). A middle wall divided the box into two equal areas with a small opening (15 \times 15 cm) located in the bottom corner to allow access between both sides of the arena. The side of the arena with the opening in the middle wall also had the only opening to outside the arena, a 10-cm \times 10-cm opening with an outer sliding door. Brackets were secured on either side of the door to permit the animal transfer cage to be directly attached to the arena. Once the animal transfer cage was attached, the sliding door could be opened to allow the test animal access to the arena.

As some of the odors tested were very volatile, materials to construct the arena were chosen based on their properties of low absorption and ease of

cleaning. The arena walls, door, and animal transfer cage were constructed of stainless steel. The arena had no bottom and was set on a sheet of white Formica. Following any animal trial, the arena was cleaned with a combination of bleach/detergent/water, then rinsed with water and sprayed with ethanol to evaporate any residual odors. The arena and camera were located in a separate room from the animal housing room, where temperature, lighting, and air circulation could be controlled separately.

The video camera was situated on a tripod directly above the middle of the arena. A television located outside the testing room was used for live viewing. During video recording, a low-intensity red-filtered light simulated nocturnal conditions under which the animals are normally active.

Test Procedure. Following pilot trials with nontest animals, it was decided to test and record individuals over a 60-min period. Only one predator odor was tested per day to reduce possible residual odor effects. This design allowed one odor and five individuals to be tested per day during the 12-hr dark phase (1800–0600 hr) when the animals are normally more active. The procedure was divided into two phases encompassing 10 days each. Each phase was identical in procedure and order of odor compounds tested. This schedule was chosen to try to prevent any effect that may occur with time, as individuals tested in the final trials will have been housed for three weeks longer than those tested initially. The phases were also scheduled as close together as possible to further reduce any time effects.

Each test animal was preexposed to the arena on the two days prior to the test day. This procedure decreased any novel effect the arena environment may have had on the individual. The preexposure trials were 15 min in duration and were also recorded on video tape. The only differences in preexposure trials from odor trials were a shorter duration, an absence of odor compounds, no prior food deprivation, and they were performed during the latter quarter of the 12-hr light period.

Prior to the day of odor testing, animals were food-deprived for 24 hr to increase their motivation to feed. This is a common procedure in laboratory trials investigating rodent behavioral responses (R. J. Blanchard, personal communication).

For the odor testing, 10 μ l of a given compound were pipetted into a urethane vial, with the odor released through a small hole in the cap of the vial. The only exception to this procedure was for the mongoose feces treatment, in which \sim 1 g was placed directly into the vial with two drops of water (\sim 0.02 ml). The odor vial was attached to the outside of a bowl that contained a measured quantity of coconut bait. The bowls were then placed in the corners of the arena, against the wall opposite from the animal transfer cage (Figure 1). Each trial had one vial containing the test chemical and the other containing water. For each treatment group, the placement of the test odor was randomly

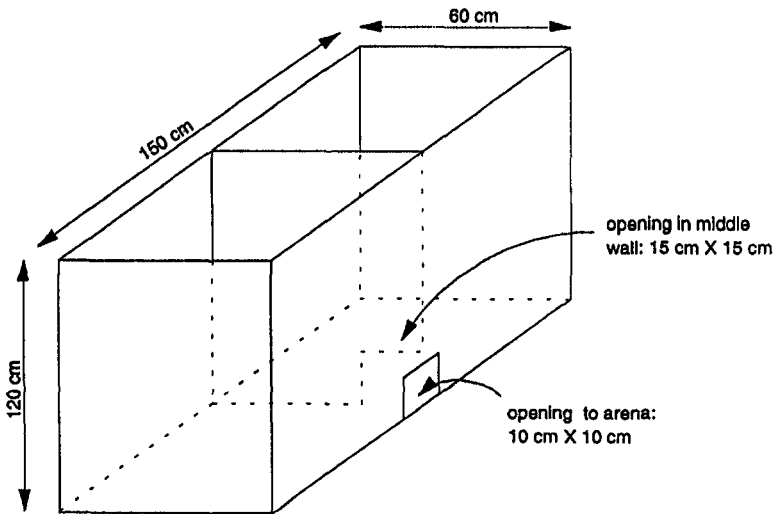
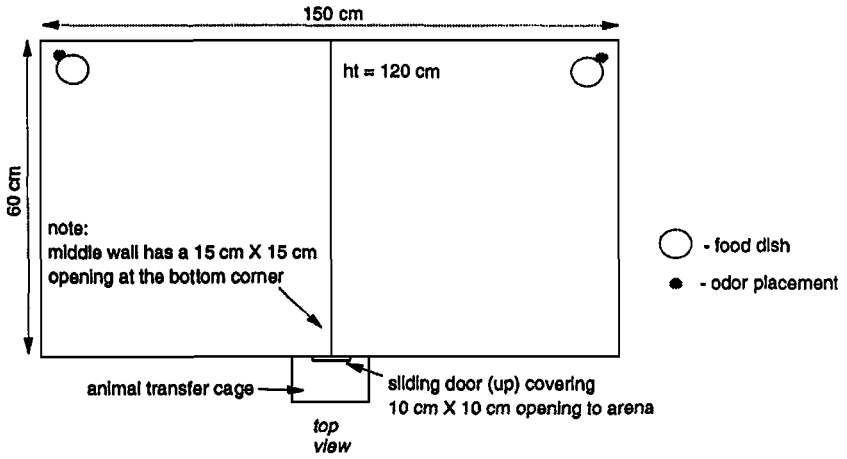


FIG. 1. Laboratory testing arena design for evaluation of predator odors to elicit an avoidance response in the roof rat (not to scale).

located for the first subgroup and placed on the opposite side for the second subgroup. This assignment reduced any bias for either side.

On the test day, the individual was moved from the animal room to the test room with the animal transfer cage. The individual was left undisturbed for 4 min to allow the subject to rest following the transfer procedure. The duration of rest time was determined based on discussions with Dr. R. J. Blanchard (personal communication) and time constraints. Using the television, the observer would record information while the animal was being video-taped, while further data were recorded during subsequent review of the tapes. Each test animal was recorded for 60 min after opening the sliding door. After each trial, the animal was returned to the animal housing room, and the arena dismantled for cleaning. The coconut bait was checked for signs of feeding and reweighed to measure consumption during the trial.

Predator Odors. Chemical compounds to be tested as repellents were originally derived from predator species, commonly from the anal scent gland, urine, or feces. The compounds have generally been identified either from extracts of these secretions or from the volatiles that emanate from them. The components believed to have semiochemical activity were then prepared synthetically. All of the odor constituents (semiochemicals) tested were synthetic liquids except for mongoose feces, which were collected from freshly voided material. The semiochemical compounds were synthesized at >90% purity by Industrial Research Limited, New Zealand and Phero Tech Inc., Delta, British Columbia, Canada. A list of the odors, an abbreviation, and their original source are given in Table 1.

Statistical Analysis. The results were analyzed as a fixed-effect randomized-block design with sex being a blocked factor. Blocking sex was performed because previous laboratory studies with the roof rat found differences between male and female consumption (Sugihara et al., 1995). For the variables that took into account the "side" factor, a three-factor repeated measures analysis of variance (ANOVA) was used with sex and treatment as the two nonrepeated factors. Variables that did not use side as a factor were analyzed with a two-factor ANOVA (sex and treatment). See Table 2 for details regarding the specific analysis of the variables measured.

The univariate repeated measures analysis has similar assumptions to the regular ANOVA. However, this analysis also assumes circularity among the levels of within-subject factor (von Ende, 1993). The within-subject factor in this case was "side," and as there were only two levels of this factor, we assumed that the difference between these two factors equaled the same value for each treatment level. This was based on the graphical representation of the descriptive statistics "by side." As the sequence of treatment levels was random and we assumed no carryover effects on the variables measured from one treatment to the next, the circularity assumption was probably met (von Ende, 1993).

TABLE 1. CHEMICAL NAME, ABBREVIATION, AND SOURCE OF PREDATOR ODORS TESTED IN LABORATORY EVALUATION

Chemical name	Abbreviation	Source
2,2-Dimethylthietane	DMT	mustelid (<i>Mustela</i> spp.) anal scent gland
3,3-Dimethyl-1,2-dithiolane	DMDIT	mustelid (<i>Mustela</i> spp.) anal scent gland red fox feces
Isopentenyl methyl sulfide	IPMS	red fox urine
<i>Herpestes auro punctatus</i> feces	MONG	mongoose feces
4-Mercapto-4-methylpentan-2-one	MMP	red fox urine and feces
(±)-3-Propyl-1,2-dithiolane	PDT	stoat (<i>Mustela erminea</i>) anal scent gland
(±)-2-propylthietane	PT	stoat (<i>Mustela erminea</i>) anal scent gland
2-sec-butyl- Δ^2 -thiazoline	SBT	mouse aggressor hormone
(<i>E,Z</i>)-2,4,5-Trimethyl- Δ^3 -thiazoline	TMT	red fox feces

The "time spent" variable was analyzed as two-factor nonrepeated ANOVA because the temporal nature of the data would violate an assumption in the repeated measures analysis. As the time a subject spends on one side is inversely related to the time it spends on the opposite side, the side data becomes less independent (R. Engeman, personal communication). The level of significance (α) was set at the 0.05 level for all ANOVAs. All statistical analysis was performed with the statistical program SAS (SAS Institute, 1988).

TABLE 2. VARIABLES MEASURED AND ANALYSIS TECHNIQUE USED TO EVALUATE LABORATORY TESTING OF PREDATOR ODORS

Variable	Analysis method
Time to emerge	two-factor ANOVA
Time to first eating bout	two-factor ANOVA
Total time spent in arena	two-factor ANOVA
Number of eating bouts	three-factor repeated measures ANOVA
Consumption	three-factor repeated measures ANOVA

RESULTS

Arena Bioassays. Although significant differences were not detected at $\alpha = 0.05$ ($P = 0.13$) for time elapsed to arena entry, the data were graphed with sexes grouped to assess trends (Figure 2). The mean (\pm SE) for entry times of rats exposed to DMDIT (explanations of abbreviations here and following can be found in Table 1) (97 ± 23 sec) and IPMS (93 ± 27 sec) were greater than for rats in the control group (39 ± 16 sec).

For time elapsed to first eating bout, no significant difference was detected between treatment groups ($P = 0.19$). Again, the data were graphed to assess potential trends (Figure 3). The mean (\pm SE) elapsed times to first eating bout for rats exposed to DMDIT (20.6 ± 7.2 min), MMP (19.3 ± 7.4 min), MONG (15.7 ± 7.1 min), PT (15.1 ± 6.4 min), SBT (17.3 ± 6.2 min), and TMT (21.1 ± 6.8 min) were greater than that for rats in the control group (6.2 ± 2.5 min). These six treatment groups were also the only treatments with animals that did not eat throughout the odor trial.

There were no significant differences ($P = 0.16$) found with respect to the time spent variable by side or by treatment. Because there were no side or sex differences for the total time spent, the data were sex and side grouped (Figure 4). This described the amount of time spent in the arena as opposed to within the covered transfer cage. There were observable trends in the amount of time spent in the arena between treatment groups and the control. The mean (\pm SE) times spent in the arena for rats exposed to DMDIT (20.0 ± 3.4 min), DMT

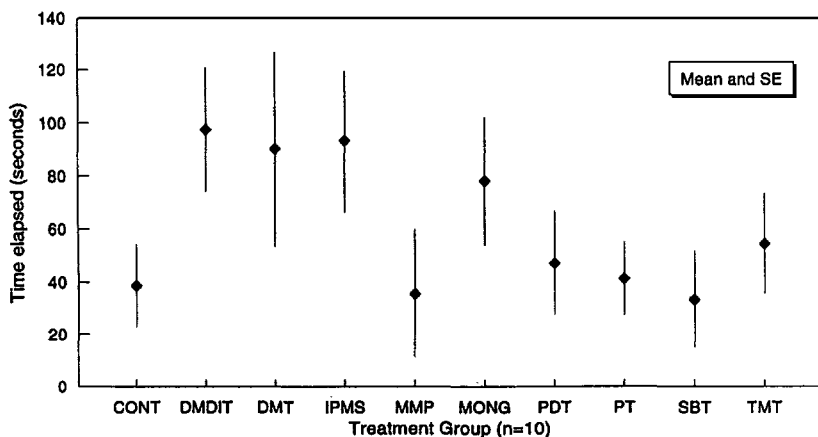


FIG. 2. Time elapsed (seconds) to initial arena entry for each of nine odor treatment groups and control (cont). Data are displayed with sex grouped. Each value is the mean \pm SE.

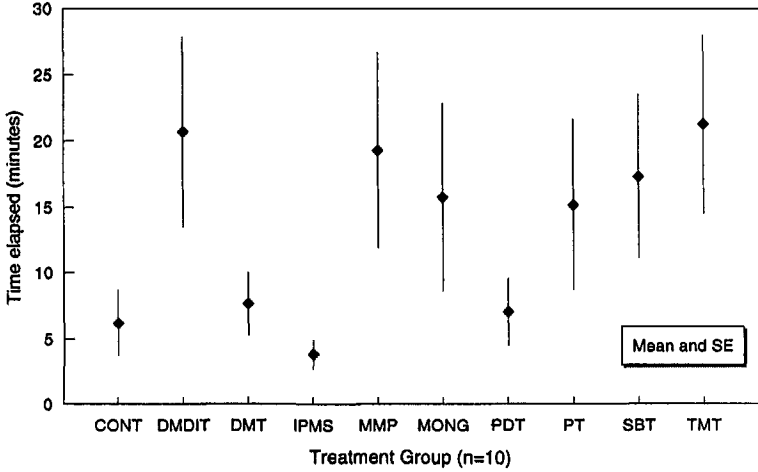


FIG. 3. Time elapsed (minutes) to first observed eating bout for each of nine odor treatment groups and control. Data are displayed with sex grouped. Each value is the mean \pm SE.

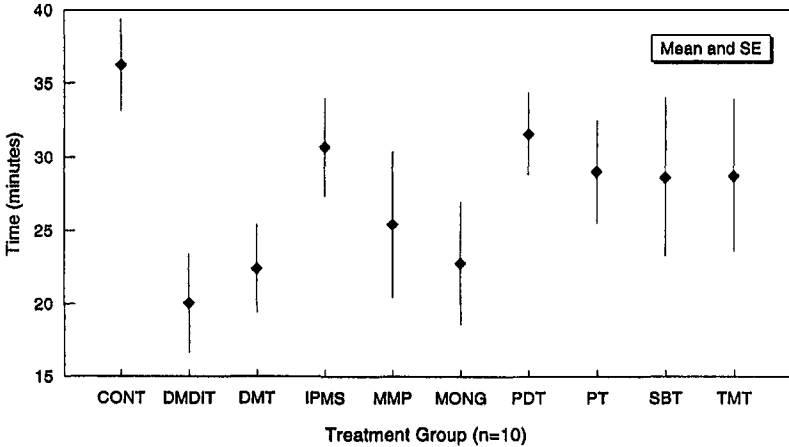


FIG. 4. Time spent (minutes) in arena (over 60 min) for each of nine odor treatment groups and control. Data are displayed with sex and sides grouped. Each value is the mean \pm SE.

(22.4 ± 3.0 min), MMP (25.4 ± 5.0 min), and MONG (22.8 ± 4.2 min) were lower than that for control group rats (36.2 ± 3.1 min).

For the observed number of eating bouts there was a significant overall treatment effect (Figure 5). Duncan's multiple comparison test indicated that rats exposed to DMDIT or TMT had fewer ($P = 0.05$) eating bouts than rats exposed to either IPMS or PDT. Neither result was different from rats in the control group. There were no sex or side differences, and these results were grouped by treatment.

There were no side or treatment differences in food consumption. However, there was a significant difference in consumption by sex. Overall, mean consumption by male rats was 0.64 g and consumption by females was 0.41 g ($P = 0.03$). The data were grouped separately for each sex and displayed in Figures 6 and 7.

Summary of Trends in Results. Individual variability may have masked any differences due to the odors, and the sample size used was not great enough to identify differences statistically. By comparing the descriptive results summarized in Table 3, different trends across the measured variables for particular treatments become apparent. We based these trends on the probability values from statistical testing as well as the graphical representation of the results (Figures 2-7). From this summary, we were able to decide which odors produced the greatest potential behavioral avoidance response. We concluded that DMDIT, TMT, MMP, and MONG treatments had the most inhibitory effect on the behavior of roof rats.

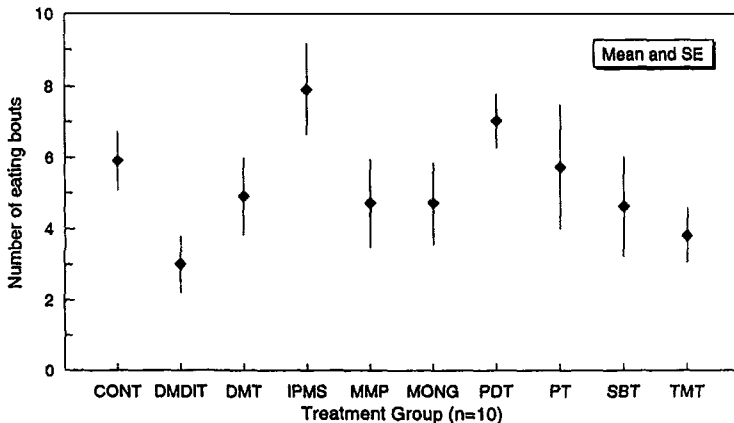


FIG. 5. Total number of eating bouts observed (over 60 min) for each of nine odor treatment groups and control. Data are displayed with sex and side grouped. Each value is the mean \pm SE.

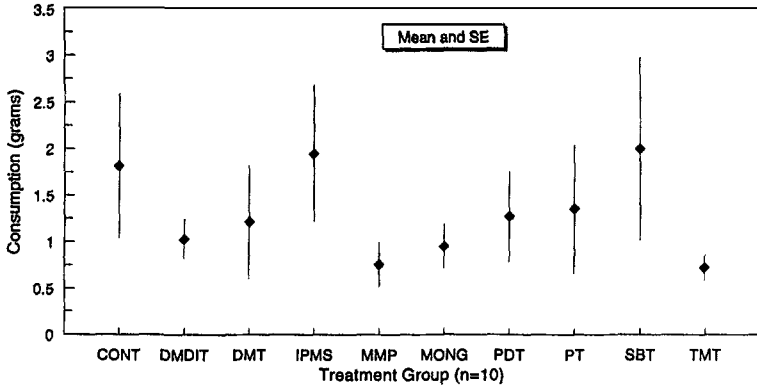


FIG. 6. Consumption (grams) by male rats for each of nine odor treatment groups and control. Data are displayed by side (treatment/control). Each value is the mean \pm SE.

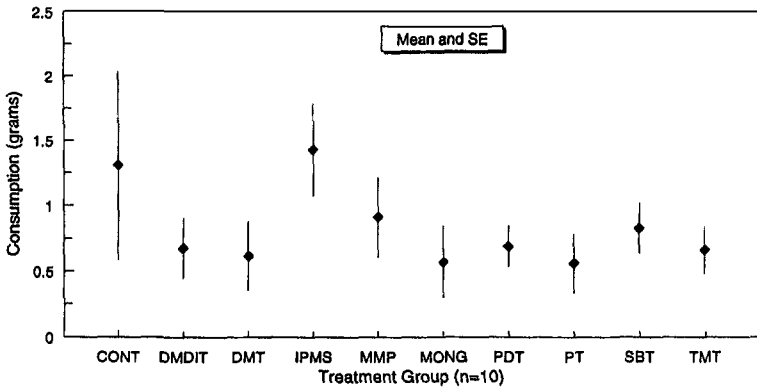


FIG. 7. Consumption (grams) by female rats for each of nine odor treatment groups and control. Data are displayed by side (treatment/control). Each value is the mean \pm SE.

DISCUSSION

The intent of this study was to detect behavioral responses of rats to the presence of predator odors. The laboratory setting allowed for the control of environmental factors that could contribute to increased experimental error and reduced power to detect a response to the predator odors. Assessment of an avoidance response was developed based on criteria utilized in previous laboratory odor studies.

TABLE 3. SUMMARY OF TRENDS IN ROOF RAT RESPONSE TO TREATMENTS RELATIVE TO CONTROL GROUP RESPONSE^a

Observation	Odor										
	DMDIT	DMT	IPMS	MMP	MONG	PDT	PT	SBT	TMT		
Increased time to first entry ($P = 0.13$)	×	+	×	-	+	-	-	-	-		
Increased time to first eating bout ($P = 0.19$)	×	-	-	×	+	-	+	×	×		
Less time spent in arena ($P = 0.16$)	×	×	+	×	×	+	×	+	+		
Lower number of eating bouts ($P = 0.05$, no differences from control)	×	-	-	-	-	-	-	-	×		
Lower consumption—males ($P = 0.03$, sex difference)	-	-	-	×	-	-	-	-	×		
Lower consumption—females ($P = 0.03$, sex difference)	-	-	-	-	-	-	-	-	-		

^aBased on P values and descriptive results of Figures 2-7; X = difference; + = slight difference; - = similar results.

Many odor studies involving small rodents take place in a controlled laboratory setting, where behavioral responses can be observed directly. Some studies have combined the observed behavioral information with physiological measures such as changes in plasma hormone levels (Vernet-Maury et al., 1984). Other studies have focused on more quantitative responses to odors such as the amount of food consumed. Mountain beaver (*Aplodontia rufa*) showed reduced consumption from bowls scented with coyote (*Canis latrans*) urine compared with control bowls (Epple et al., 1993). Avoidance response of pocket gophers to stoat scent was determined by number of captures between scented and unscented traps (Sullivan and Crump, 1986). Chance and Mead (1955) showed that a greater stimulus change produced greater delays before a lab rat would start eating.

Previous laboratory odor studies have attributed fear responses to particular observed behaviors. However, there are often discrepancies in the interpretation of particular behavioral responses, and various researchers have attributed different meanings to similar activities. The observed behavior of defecation has been identified as a fear response (Vernet-Maury et al., 1984) and also as a nonfear response. Grooming and jumping are also two behaviors that are difficult to qualify as a stress response. Grooming observed in the presence of predator odors has been described as a defensive response. Others have considered grooming to occur once the animal considers the surroundings safe (Vernet-Maury et al., 1984). Jumping is a common activity for roof rats and is often considered an exploratory behavior, especially in novel surroundings. Many of the common behavioral observations such as stretch, sniff, and rearing also appear to be more exploratory in nature and not necessarily indicative of a phobic response. Because of ambiguous interpretation of these behaviors, they were not used in this study. However, food consumption has been tested as a measure of avoidance of predator odors (Calder and Gorman, 1991; Epple et al., 1993; Heale and Vanderwolf, 1994). In our study, food consumption and other discrete observations were used to conclude whether or not the predator odors tested produced the desired response.

There are a wide range of responses one could potentially observe and interpret, and this study focused more on quantitative measurements. There is no preferred standard procedure to test the effect of predator odors, and hence an arena was designed to allow the observation of many likely behaviors. We also wanted to allow the individual a safe zone provided by access to a covered transfer cage. This design provided the individual with cover, food, and an exploration area, while its behavioral responses were observed in a two-choice situation. We assumed that if a particular odor signaled danger to a rat, then it would try to avoid the odor by delaying entry into the odor-treated arena, delaying time to first eating bout, spending less time on the treated side, and eating less from the treated side of the arena.

The results from the statistical analysis indicated no differences in the observed responses to predator odor treatments. We feel that much of the potential odor effects may have been hidden by the high individual variability observed in these rats. This variability in roof rats probably increased experimental error and reduced the power of statistical tests to detect significant results. This known variability may provide the rationale for raising α levels to increase the power of the test, while recognizing the elevated potential for type I errors. Recognition of this issue as well as the near significant statistical results ($P \approx 0.15$, see Table 3), suggested further consideration of the data.

The roof rat is considered a generalist species able to adapt readily to changes in the environment. This flexibility is partly due to the high variability in individual behavior. During the preliminary trials, differences in the response to the novel arena were observed. Some individuals spent the majority of time in the covered transfer cage, others ventured into the arena very cautiously, while some darted quickly between the two sides and the transfer cage. This variation between individuals has been suggested to explain *Rattus* species' adaptability (Ewer, 1971). Having a broad range of individual behavior responses allows the population as a whole to adapt readily to changes in the environment.

Other differences in responses may have occurred depending upon the type of predator odor tested. Jedrzejewski et al. (1993) showed different patterns of behavioral response of bank voles (*Clethrionomys glareolus*) to seven different predator odors. They found that voles responded differently to various species of carnivores and summarized these differences in a behavioral response table. Vernet-Maury et al. (1984) compared responses to predator odors using a behavioral score, based on whether the observation was considered that of a stress response or not. This technique allowed the combination of responses to give a final behavioral score with which to compare the odors. We followed a similar approach in combining the different response variables into a summary table (Table 3) to assist in interpreting the results.

The odors of interest were DMDIT, TMT, and MMP, all unfamiliar (in recent evolutionary times) synthetic odors, as well as MONG, a predator odor familiar to the roof rat. DMDIT delayed the time spent exploring/searching in the arena, increased the time elapsed to first eating bout, and reduced the time spent in the arena, the number of eating bouts, and the total consumption. MONG had similar results, although the total number of eating bouts was not different from the control group. TMT produced the greatest fear response in previous laboratory studies with rats (Vernet-Maury et al., 1984); this latter study also found that MMP and DMDIT produced a fear response, supporting the descriptive trends in this study.

Although no trials were performed to test for habituation, the results indicate that the roof rat tends to avoid mongoose feces, a familiar predator on most of the Hawaiian islands. The test rats had probably encountered mongoose odor

before being captured, and their apparent avoidance responses in the arena suggested that this fecal odor was recognized. This avoidance in the testing arena provided some evidence that the wild roof rat has not habituated to mongoose odor. These indications of avoidance in the testing arena may also reflect what has been demonstrated in the field. A recent live-trap study found lower capture success of roof rats in traps that had previously captured a mongoose (Tobin et al., 1995).

The trends in avoidance of some of the synthetic odors tested resembled those for the mongoose odor. Based on the live-trap study of Tobin et al. (1995), it is expected that the synthetic predator odors would produce a similar avoidance response in the field. Although the synthetic odors lack any positive reinforcement in the field, we believe that an avoidance response will be observed initially. This prediction is supported by studies that indicate rodents have an innate recognition of predator odors. Cattarelli and Chanel (1979) demonstrated the greatest olfactory "awakening influence" for lab-reared Wistar rats occurred with red fox fecal odor. Vernet-Maury et al. (1984, 1992) have also demonstrated a fear response in lab rats when exposed to various predator odor chemicals. Orkney voles (*Microtus arvalis*), which have not been in contact with predators for generations also displayed an avoidance response when exposed to carnivore odors (Gorman, 1984). Whether this is a response to a particular common semiochemical is unknown, but definite behavioral responses have been observed in rodents exposed to various predator odors. The responses measured in the laboratory suggest an avoidance behavior by the wild Hawaiian roof rat to synthetic predator odors and support efforts to further test the odors in field trials.

CONCLUSIONS

Our laboratory bioassays indicated that responses to a predator odor could be detected by combining the results from various measures of observed behaviors. This descriptive summary approach has been used to combine results from various types of measurements (i.e., behavioral observations) and utilizes non-parametric analysis (Vernet-Maury et al., 1984). In the odor-testing arena, roof rats were observed to delay before entering, delay from first eating bout, spend less time in the arena, show a lower number of eating bouts, and consume less food in the presence of DMDIT odor. Mongoose fecal odor also produced similar avoidance responses, although they were not statistically significant. TMT and MMP synthetic predator odors also had avoidance trends in roof rats. These results support other laboratory findings in which avoidance or fear responses were recorded in rodents while in the presence of predator odors. A study with the same laboratory arena with modifications to the design and pro-

cedure found no difference in variables measured while testing mongoose odor treatments (Tobin et al., 1997). The nonsignificant results agree with the findings in our study. However, different variables were measured over a different time period, which may have contributed to a lack of observed descriptive trends. This same study (Tobin et al., 1997) also found lower capture rates in live-traps soiled with mongoose feces in the field portion of the study.

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