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Influence of trap type, size, color, and trapping location on the capture of the New Guinea sugarcane weevil, *Rhabdoscelus obscurus* (Coleoptera: Curculionidae)

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ABSTRACT

The New Guinea sugarcane weevil (*Rhabdoscelus obscurus*) (Boisduval) (Coleoptera: Curculionidae) is a pest of palm plantations, ornamental nurseries, and sugarcane. Field and laboratory studies explored the effects of trap characteristics such as design, size, color, visual and olfactory cues, and location on capture of *R. obscurus* in date palm plantations and ornamental nurseries at five locations (Dededo, Mangilao, Malojloj, Inarajan, and Yigo) on Guam, USA. Ramp and ground traps captured similarly, and both captured significantly more adults than bucket and pitfall traps. For economy and ease of handling, the ground trap was used for all further experiments. Larger ground traps (40 × 25 cm and above) were more efficient than smaller ones (30 × 15 cm) in capturing adults in field. Of the eight trap colors tested in the field, brown proved most effective, followed by, in order, yellow, red, gray, blue, black, white, and green; russet was more effective than other shades of brown. Mixing paint of the other colors with brown paint did not significantly improve their performance. In contrast, laboratory color-choice tests indicated, *R. obscurus* preferred black traps over those of other colors and showed no preferences among different shades of black. Again, mixing paint of the other colors with black paint did not significantly improve their performance. Russet brown ground traps baited with pheromone lures caught significantly more adults than did identical traps without lures. Traps strapped to trees caught significantly more individuals than traps placed between trees or away from trees. Russet-brown ground traps 40 × 25 cm appeared to be the most effective at catching *R. obscurus* in the field, whereas otherwise identical black -colored traps were more efficient indoors.

INTRODUCTION

The New Guinea sugarcane weevil, *Rhabdoscelus obscurus* (Boisduval) (Coleoptera: Curculionidae) is a very serious pest of ornamental palms and coconut plantations on the Mariana Islands and other Pacific islands (Muniappan et al., 2004). Its incidence is so high on ornamental nursery plants, betel nut (*Areca catechu* L.), and coconut (*Cocos nucifera* L.) that several growers have given up cultivation in frustration (Reddy et al., 2005a). Incidence is extremely high during the hot and dry season. Even small populations of this weevil can cause severe damage, and they are a year-round pest in warm climates (Sallam et al., 2004).

Because the weather in Micronesia is mostly dry and hot throughout the year, *R. obscurus* infestation has been very severe (Bianchi & Owen, 1965). Guam and other Micronesian islands are therefore in the midst of a decline in nursery and ornamental plant production. According to feedback from local farmers and homeowners in the region, extension faculty of the University of Guam, and personal observation by the senior author, thousands of ornamental nursery and betel-nut plants are dying as a result of *R. obscurus* infestation. Recently, *R. obscurus* has begun attacking coconut palms. Although some control methods exist, chemical application is both undesirable and expensive (Robertson & Webster, 1995). In the absence of appropriate, effective control, these *R. obscurus* populations are likely to cause widespread or even complete loss of nursery and betel-nut production in Micronesia this region and others. Although a parasitoid, *Lixophaga sphenophori* (Villeneuve) (Diptera: Tachinidae), from Maui (Hawaii) was introduced on Guam in 2005 for the control of *R. obscurus*, it seems not to be established yet. Farmers, homeowners, and commercial firms in this region apply insecticides (Dimethoate, Acephate, Carbaryl, Malathion, Naled, and Lambda-cyhalothrin) up to 20–30 times per cropping period, particularly in ornamental nurseries, these costly measures have been associated with ecological and toxicological hazards. Ecologically sound and cost-effective semiochemical (pheromone)-based trapping methods must therefore be developed, implemented, and adopted by growers.

Both male and female *R. obscurus* produced a pheromone only when fed on sugarcane. Virgin males four to six days old fed on sugarcane produced a pheromone that attracted only females (Chang & Curtis, 1972), but the same males at 12 to 16 days old attracted both sexes. Giblin-Davis et al. (2000) identified the pheromone of Hawaiian *R. obscurus* as 2-methyl-4-octanol and the equivalent pheromone compounds for Australian *R. obscurus* population as 2-methyl-4-octanol, (*E*2)-6-methyl-2-hepten-4-ol (rhynchophorol), and 2-methyl-4-heptanol, but 2-methyl-4-heptanol was not included in their trapping method for *R. obscurus* because it elicited no behavioral effect.

Giblin-Davis et al. (1996) reported that baits of approximately 3 mg per day of synthetic pheromone in combination with insecticide-treated plant tissue were highly attractive to palm weevils, including *R. obscurus*. In our previous study, traps baited with lures from the Australian geographical population caught significantly more weevils than traps baited with lures from the Hawaiian *R. obscurus* population, suggesting that the Guam population is reacting similarly to the Australian population (Muniappan et al., 2004). Moreover, this population is predominantly present in the north because the majority of the commercial nurseries are located there. We also observed in that study that addition of ethyl acetate to the pheromone lures as a synergist significantly increased trap catches of *R. obscurus*, but the pheromone-based trapping method we previously developed resulted in poor catches and did not help in controlling *R. obscurus* (Reddy et al., 2005a).

Few data are available on the monitoring of *R. obscurus* with pheromone traps, so improving trap performance and make traps more reliable tools for integrated control programs will require characterizing the factors that affect trap capture efficiency. The purpose of the study reported here was to determine the effects of trap design, size, color, and location so as to develop an efficient pheromone-based trapping method for controlling *R. obscurus* on Guam and in other parts of world.

MATERIALS AND METHODS

Experimental sites

The experiments were carried out on the island of Guam (USA) at five locations: Bob's Nursery, Dededo (13.52°N, 144.84°E); Landscape Management Systems, Mangilao (13.43°N, 144.80°E); The Green Thumb Plant Nursery, Malojloj (13.39°N, 144.45°E); and the University of Guam's Agricultural Experiment Stations (AES), Inarajan (13.15°N, 144.30°E) and Yigo (13.54°N, 144.89°E). The prevailing temperature, relative humidity, and wind velocity were recorded during the experimental period. A large part of the land area of these locations is covered entirely with ornamental nursery, and plantation palms (predominantly date palms) were used for experimentation.

Trap designs

A commercially available ramp trap and three other, locally fabricated trap types (ground, bucket, and pitfall) were evaluated (Figure 1).

The ramp trap used was commercially available from ChemTica Internacional S.A. (San José, Costa Rica). It was made of durable yellow Perspex and consisted of two box-shaped components, each 14 cm wide by 4 cm high (inside dimensions), one, open side up, forming the floor of the trap and the other, open side down, forming its roof and supported on short pillars at the corners (Reddy, 2007). Wide Perspex ramps on all four sides led up to the rim of the lower box, which rested on the ground. The pheromone lure and ethyl acetate were attached to the ceiling of the trap with a piece of vinyl-clad steel wire (the same wire used in all trap types), and two cut pieces of sugarcane were placed inside the trap. The floor of the trap was treated with a permethrin.

The ground trap was constructed in our laboratory from a 120- × 60- × 0.5-cm piece of white corrugated plastic board, with a 50- × 8-cm slitted baffle fitted at the top to prevent borers from escaping (Reddy et al., 2005b). The lower outer edges of the ground traps were shielded with soil to prevent weevils from crawling under the traps. The pheromone and ethyl acetate (*Rhynchophorus palmarum* lure) lures were suspended inside the traps on wires hung from the top. Two cut pieces of sugarcane, 12 cm long, were placed directly in the ground trap and replaced with fresh canes weekly. The inside bottom of the trap was treated with a 5-ml spray of permethrin (0.75 ml/1 liter) to kill the attracted *R. obscurus*. Lures were changed at 4-month intervals (Reddy et al., 2005a).

Pitfall traps were cylindrical, translucent white plastic cups (10-cm diameter, 1.5-liter capacity) (Reddy et al., 2009). Four 24-mm drainage holes were drilled at 90° intervals in the sides of the cup, at least 5 cm above the bottom. The pheromone and ethyl acetate lures was suspended from the top of the cup on a wire (12 cm long) threaded through a 3-mm hole. The floor of the trap was treated with a 5-ml spray of permethrin. The traps were placed in 10-cm-deep holes into the ground, so that the upper edge of the cup was at the level of the soil surface.

Each plastic bucket trap consisted of a 19.0-liter white plastic tapered container (37.0 cm height × 30.0 cm ID base; Reddy et al., 2005a). Two holes (17.5 cm tall and 7.5 cm wide) were cut in opposite sides of the container (14.75 cm above the soil surface) to allow weevil entry into the trap. Twenty drainage holes, each 3 mm in diameter, were made in the floor. A pheromone and ethyl acetate lure was suspended in the trap from wires attached to opposite sides of the rim. Two fresh sugarcane sections were placed directly in the bucket trap.

Semiochemical lures

The pheromone and ethyl acetate lures were stored in a refrigerator until use. The pheromone lures ((*E*2)-6-methyl-2-hepten-4-ol and 2-methyl-4-octanol) were sealed in polymer membrane release devices optimized for the Australian population of *R. obscurus*. The release rates and method of use of these lures were as previously described (Reddy et al., 2005a).

Effect of trap design

Ground, ramp, pitfall, and bucket traps with pheromone and ethyl acetate lures were placed at the five locations about 10 m apart on the ground in ornamental nursery and betel-net (four of each trap type were deployed at each location). Trapped *R. obscurus* were counted and removed weekly. The traps were washed and rinsed, and new fresh cut sugarcane was added. The traps were randomized across each field to preclude any possible local location effect. Concurrently, traps without lures were used as controls. The experiment was carried out from June to September 2008.

Effect of trap size

The effectivenesses of four different sizes of ground traps (60 × 40, 50 × 30, 40 × 25, and 30 × 15 cm) were compared. In each village, one trap of each size was set up, and their locations were rotated every week to preclude any local location effect. The experiment was conducted from October to December 2008.

Effect of trap color

Trap color characteristics were determined with a Konica Minolta CR-410 Chromameter (Minolta Instrument Systems, Ramsey, NJ). The hue angle and chroma and the average of three readings for each color were recorded. The hue angle indicates the sample color, whereas the chroma provides a measure of the color intensity, and these were calculated according to the equations of Wrolstad et al. (2005). The hue angle is expressed on a 360º grid on which 0º = red, 90º = yellow, 180º = green, and 270º = blue. Trap color measurement values are given in Table 1.

Because *R. obscurus* attacks plants both indoors and outdoors, we carried out four field and two laboratory experiments. Paint of eight commercially available colors (BEHR Process Corporation, Santa Ana, CA, USA) was purchased locally from Home Depot. Four traps of each color were grouped together at each of the five locations listed above.

For the first field experiment, ground traps of the 40- × 25-cm size were painted blue (Sailboat: S-H-590), yellow (Sunny Summer: S-G-380), gray (Beluga: 770F-7), green (Pine Grove: 460B-7), brown (Bear Rug: S-G-790), red (Pure Red: 2-8610), white (Ultra-Pure White: 2-9-850), or black (Pure Black: 2-8620). The experiment was carried out from January to March 2009.

For the second field experiment, ground traps of the same size were painted with (1:1) mixtures of brown with each of the other colors. Traps of colored with unmixed brown paint served as controls. Color measurements for the mixed-color traps are given in Table 2. The experiment was carried out from April to June 2009.

The two indoor experiments on trap color were conducted in a laboratory 10 m long × 6 m wide × 3.5 m high. Because *R. obscurus* is known to be nocturnal (Napompeth et al., 1972), the field-collected adults are fed and reared under reversed photoperiod for 2 weeks before to start the experiment in the laboratory. This is to facilitate experiments during the daytime. The tests were run in the darkened laboratory (dimply lighted) between 1200 and 1730 hours with 40- × 25-cm ground traps of different colors, baited with pheromone and ethyl acetate lures. The trap to be tested was placed on the floor of the laboratory 2 hours before the release of the adults, so that pheromone and ethyl acetate vapors could spread throughout the laboratory. Forty adults were then released into the laboratory, about 3 m from the trap. The number of adults trapped during the succeeding 3 hours was recorded. Trapped beetles were removed after capture and discarded. Uncaptured insects were removed before the next trial, and we used fresh adults for each replicate to avoid pseudoreplication.

For the first indoor experiment, brown, black, gray, yellow, red, white, green, and blue trap colors were tested individually, four replicates per color. The experiment was carried out from June to July 2009. For the second indoor experiment, the traps were painted with (1:1) mixtures of black with each of the other colors. Measurement values for the colors blended with black are given in Table 3. Pure black traps served as controls. The experiment was carried out from July to August 2009.

For the third field experiment, 40- × 25-cm ground traps were painted with different shades of brown; dark brown, mahogany brown, russet brown, saddle brown, and light brown were evaluated. Color measurement values for the different shades of are given in Table 4. The shades were tested individually (four traps per shade; one trap per location) at the same five villages. The experiment was conducted from September to November 2009.

For the fourth field experiment, 40- × 25-cm ground traps were painted with four different shades of black (pure black, mix black, black medium, black thick). Color measurement values for different shades of black are given in Table 5. The shades were tested individually (four traps per shade, one trap per location) at the same five villages. The experiment was conducted from August to September 2009.

Relative effects of visual and olfactory cues

To determine the comparative importance of the visual and olfactory components of attraction, we compared the efficacy of russet brown 40- × 25-cm ground traps either baited with pheromone lures or unbaited. Four traps of each treatment were deployed at each of the same five villages, and the experiment was carried out from December 2009 to February 2010.

Effect of local trap location

Russet brown 40- × 25-cm ground traps baited with pheromone and ethyl acetate lures were placed on the ground but strapped (with wire) to betel net trees, on the ground between trees, or on the ground 10 m from the nearest tree. Each treatment was replicated four times at each village, and the experiment was conducted from March to May 2010.

Statistical analysis

The data were analyzed with the general-linear-model procedure of SAS Version 9.13 (SAS Institute, 2009). Because all the response variables used in the experiments were counts, a one-way Poisson ANOVA model was fitted by The GLIMMIX Procedure. For the comparisons of the means, the least square means test was used to make multiple comparisons for significant differences between treatments at $P = 0.05$.

RESULTS

Effect of trap design

Traps of all the designs tested, baited with pheromone lures, captured *R. obscurus*, but designs differed in capture rate. Ramp and ground traps captured significantly more *R. obscurus* than bucket and pitfall traps ($F = 37.44$, $df = 2$, $P < 0.005$; Figure 2), and buckets traps caught significantly more than did pitfall traps. Traps without lures captured no adults. During the experimental period, the average temperature was 27.0°C, the average relative humidity 65–80%, and the average wind velocity 5.6 m/s. Although ground and ramp traps were equally effective, the ground trap was selected for all further experiments because it less inexpensive and more easily fabricated.

Effect of trap size

Ground traps 30 × 15 cm caught significantly fewer adult *R. obscurus* (6.6 ± 0.8 adults/trap) than did the three larger sizes (mean of 10.1 ± 0.4, 11.2 ± 1.2, and 10.4 ± 0.7 adults/trap for 60 × 14, 50 × 30, and 40 × 25 cm, respectively), which did not differ from one another ($F = 4.32$, $df = 3$, $P < 0.005$; Figure 3). During the experimental period the average temperature was 28.4°C, relative humidity 65–80%, and wind velocity 4.3 m/s. For economy and ease of handling, 40- × 25-cm traps were chosen for further study.

Effect of trap color

In the field experiments, brown ground traps were most attractive to *R. obscurus* ($F = 4.47$, $df = 7$, $P < 0.01$; Figure 4), catching, on average, 11.4 ± 1.3 adults/trap, significantly more than traps of any of the other colors tested. No significant differences were observed among the other colors. During the experimental period, the average temperature was 27.8°C, the relative humidity 65–80%, and the wind velocity 2.6 m/s.

Mixing brown paint with the other colors did not improve their catch rates ($P < 0.05$) Traps of unmixed brown captured significantly more weevils than the traps with mixed colors ($F = 11.23$, $df = 7$, $P < 0.05$; Figure 5). During the experimental period, the average temperature was 30.4°C, relative humidity 65–80%, and wind velocity 6.8 m/s.

In the laboratory experiments, black ground traps were more attractive to *R. obscurus* than traps of any other color tested ($F = 8.72$, df = 7, $P < 0.001$; Figure 6), catching, on average, 13.5 ± 1.8 adults/trap, significantly more than brown traps (8.8 ± 0.7 adults/trap), the second most preferred. Brown traps differed significant ($P < 0.001$) from red ones, red, gray, blue, white, yellow, and green did not differ significantly. During the experimental period, the average temperature was 26.2°C, relative humidity 80–85%, and wind velocity 0.2 m/s.

Mixing black paint with paint of other colors did not significantly improve ($P > 0.05$) those colors' trapping effectiveness. Traps painted with pure black, mix black, or mix black mixed with pure black captured significantly higher numbers of adults than those painted with the other mixtures ($F = 13.44$, df = 9, $P < 0.001$; Figure 7). During the experimental period, the average temperature was 25.8°C, relative humidity 80–85%, and wind velocity 0.5 m/s.

Effect of shades of brown

The shade of brown significantly affected adult catches in ground traps ($F = 11.22$, df = 4, $P < 0.005$; Figure 8) in the field. Russet brown traps caught significantly more adult weevils (10.6 ± 0.6 adults/trap) than did other shades. Mahogany and light brown did not differ significantly in the numbers caught, whereas dark- and saddle-brown traps caught significantly fewer than the other shades (2.6 ± 0.3 and 2.5± 0.6 adults/trap, respectively). During the experimental period, the average temperature was 27.7°C, relative humidity 80–85%, and wind velocity 5.2 m/s.

Effect of shades of black

In the field, no significant difference in catch was observed between traps of different shades of black ($P > 0.05$; data not shown). During the experimental period, the average temperature was 26.3°C, relative humidity 80–85%, and wind velocity 7.4 m/s.

Effects of visual and olfactory cues

Russet brown ground traps baited with pheromone lures caught significantly more adults (10.5 ± 0.4 adults/trap) than did identical traps without such lures (3.5 ± 0.1 adults/trap) ($F = 42.32$, $df = 1$, $P < 0.01$; Figure 9). During the experimental period, the average temperature was 27.3°C, relative humidity 80–85%, and wind velocity 3.7 m/s.

Effect of trap location

Russet brown ground traps baited with pheromone lures strapped to trees caught significantly more adult weevils than identical traps placed between trees or away from trees ($F = 7.43$, $df = 2$, $P < 0.001$; Figure 10). During the experimental period, the average temperature was 26.9°C, relative humidity 80–85%, and wind velocity 8.6 m/s.

DISCUSSION

Semiochemical-based trapping method can provide a useful and viable and environmentally sound control approach for many insects, particularly wood borers, where application of insecticides is not feasible (Reddy & Guerrero, 2004, 2010). Existing pheromone-based trapping methods—the routine use of bucket traps baited with pheromone lures—have helped in monitoring of *R. obscurus* (Muniappan et al., 2004; Reddy et al., 2005a), but have resulted in only low capture rates and did not control *R. obscurus* on Guam and other Pacific islands. Recently, *R. obscurus* has been attacking coconut trees and might become uncontrollable and kill all ornamental nursery plants and palms. Moreover, little attempt has been made to determine concerning the impact of trap design on capture of *R. obscurus*. Although Sallam et al. (2007) recommended water traps for the purpose, this method proved effectual only in dry areas. Since high rainfall occurs throughout pacific, the water trap is not practical there. Optimization of trap characteristics for *R. obscurus* is therefore timely, and the optimized methods can be used in other parts of the world where this widespread pest is a problem. In our study, ramp and ground traps were more efficient in capturing *R. obscurus* than were bucket or pitfall traps. Although ramp and ground traps were equally effective, ground traps are easily made by hand from corrugated plastic and are convenient and inexpensive. Moreover, captured adults can be seen easily and removed from the trap bottom. Ground traps have proven more appropriate for use both in the field and indoors and are effective against other insects, such as *Hylotrupes bajulus* (L.) (Coleoptera: Cerambycidae) (Reddy et al., 2005b) and *Cosmopolites sordidus* (Coleoptera: Curculionidae) (Reddy et al., 2009). The influence of trap type on capture rates of other insects has been described in our previous publication (Reddy et al., 2009).

Trap size selection is important, as is the compromise among cost, ease of deployment, and trap performance (Miller & Crowe, 2009). The trap size chosen as optimal in the present study was the same as that selected for *C. sordidus* (Reddy et al., 2009). Trap-size results are not always so clearcut, however. Miller and Crowe (2009), using traps consisting of linear arrays of funnels got mixed results. They found that more *Arhopalus rusticus nubilus* (Coleoptera: Cerambycidae) and *Xyleborus* spp. (Coeloptera: Scolytidae) were caught in 16-unit traps than in 8-unit ones, that catches of *Hylobius pales* (Coleoptera: Curculionidae) in 16-unit traps were 54% lower than those in 8-unit traps, and that trap size had no effect on catches of *Xylotreches sagittatus* (Coleoptera: Cerambycidae).

Trapping location is one of the important factors that affect the trap catches. Responses of insects varies to trap placement have been demonstrated in *Cydia pomonella* (Kehat et al., 1994), *Diaphania nitidalis* (Valles et al., 1991), *Palpita unionalis* (Athanassiou et al., 2004), and *C. sordidus* (Reddy et al., 2009). In the study reported here, the traps strapped to the trees caught more target insects than did traps placed between or away from trees, suggesting that *R. obscurus* preferred to walk or crawl from the trees to the trap. This kind of behavior was observed in *H.*

bajulus-even though adults initially flew upwind in the pheromone plume, they generally walked the final distance (about 50 cm) to the source (Reddy et al.,2005b).

Nocturnal insect species have been reported to discriminate flower colors at starlight intensities, when humans and honeybees are color blind (Kelber et al., 2003). For example, *Macroglossum stellatarum* (Lepidoptera: Sphingidae) can use achromatic, intensity-related cues if color cues are absent. Even in dim starlight, however, nocturnal insects can use chromatic rather than achromatic cues to recognize flowers (Kelber et al., 2003). The fast-flying nocturnal sweat bee *Megalopta genalis* (Hymenoptera: Halictidae) relies primarily on vision and can forage and home by using visually discriminated landmarks at starlight intensities (Warrant, 2004; Frederiksen et al., 2008). Most on color vision in nocturnal insects has been confined to hawkmoths and bees, but our results showed that trap color influenced the capture efficiency of nocturnal Curculionidae (coleopteran) weevils. Our previous results showed that *C. sordidus* not only clearly prefers brown to yellow, red, gray, blue, black, white, and green but prefers mahogany to four other shades of brown. From the results presented here, we argue that *R. obscurus* can also discriminate colors, but further research effort is necessary.

Rhabdoscelus obscurus responded to baited ground traps of different colors differently in the field and indoors. In the field, *R. obscurus* preferred brown, and particularly russet, over the other colors, but indoors, black traps were favored. We have no explanation for the difference.

In conclusion, our study indicated that trap design, size, color, and trapping location are important factors affecting the response of *R. obscurus* to pheromone-baited traps. In particular, the 40- × 25-cm russet brown ground traps baited with pheromone lures and strapped to the trees are an efficient tool for catching *R. obscurus* in the field. Indoors, black, but otherwise identical, traps were most effective. These findings should be taken into consideration when mass trapping technique are developed for this important borer pest.

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Figure 1 The four trap designs used in the present study.

Figure 2 Mean (± SE) numbers of adult *R. obscurus* caught by ramp (R), bucket (B), ground (G), and pitfall (P) traps with (L) and without (N) pheromone lures. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.0001$). Means were generated from four replications. Traps with lures outperformed traps without lures, and ramp and ground traps outperformed others.

Figure 3 Mean (± SE) numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different sizes. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.05$). Bars represent means of four replicates. The smallest traps were least effective.

Figure 4 Mean (± SE) numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors in the field. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.001$). Brown traps outperformed all others. Bars represent means of four replicates.

Figure 5 Mean (± SE) numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors mixed 1:1 with brown in the field. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.01$). Adding brown to the other colors did not improve their performance. Bars represent means of four replicates.

Figure 6 Mean (± SE) numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors in the laboratory. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.001$). The means were generated from eight tests each using 30 insects. Black traps outperformed all others.

Figure 7 Mean (± SE) numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different colors mixed 1:1 with black in the laboratory. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.01$). Adding black to the other colors did not improve their performance. Bars represent means of four replicates.

Figure 8 Mean (± SE) numbers of adult *R. obscurus* caught in pheromone-baited ground traps of different shades of brown in the field. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.01$). Russet outperformed other shades of brown. Bars represent means of four replicates.

Figure 9 Mean (± SE) numbers of adult *R. obscurus* caught in russet-brown ground traps with and without pheromone lures in the field. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.0001$). Traps with lures outperformed identical traps without lures. Bars represent means of four replicates.

Figure 10 Mean (± SE) numbers of adult *R. obscurus* caught in pheromone-baited ground traps placed in different locations. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson model, least square means, $P < 0.05$). Bars represent means of four replicates.

Figure 1

Figure 2

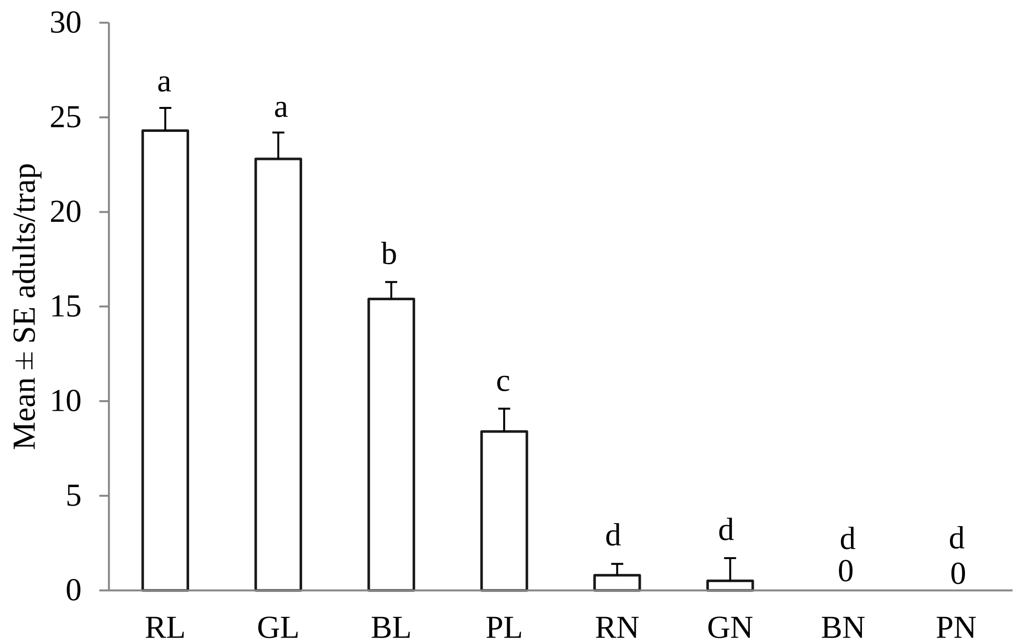

Mean ± SE adults/trap
30
25
20
15
10
5
0
a
a
b
c
d
d
d
0
d
0
RL
GL
BL
PL
RN
GN
BN
PN

Figure 3

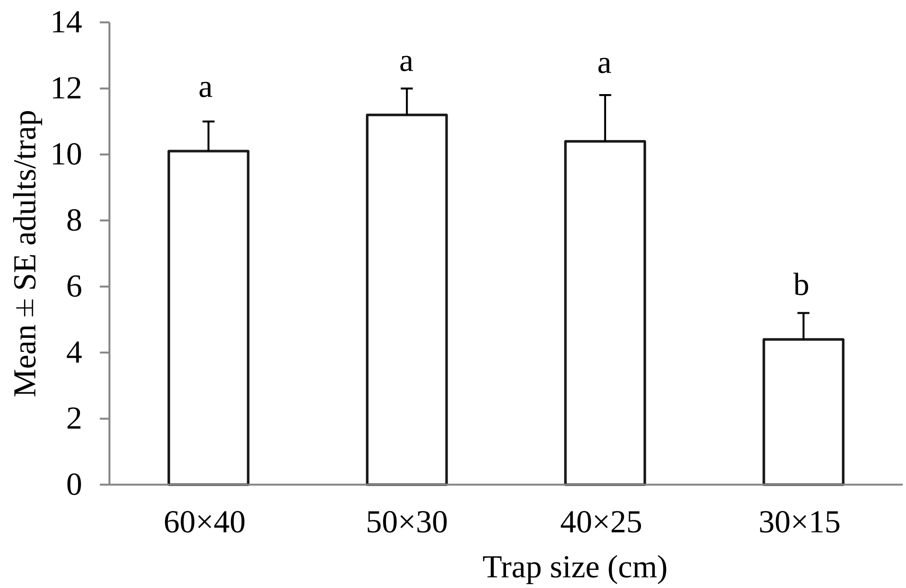

14
12
10
8
6
4
2
0
Mean ± SE adults/trap
a
a
a
b
60×40
50×30
40×25
30×15
Trap size (cm)

Figure 4

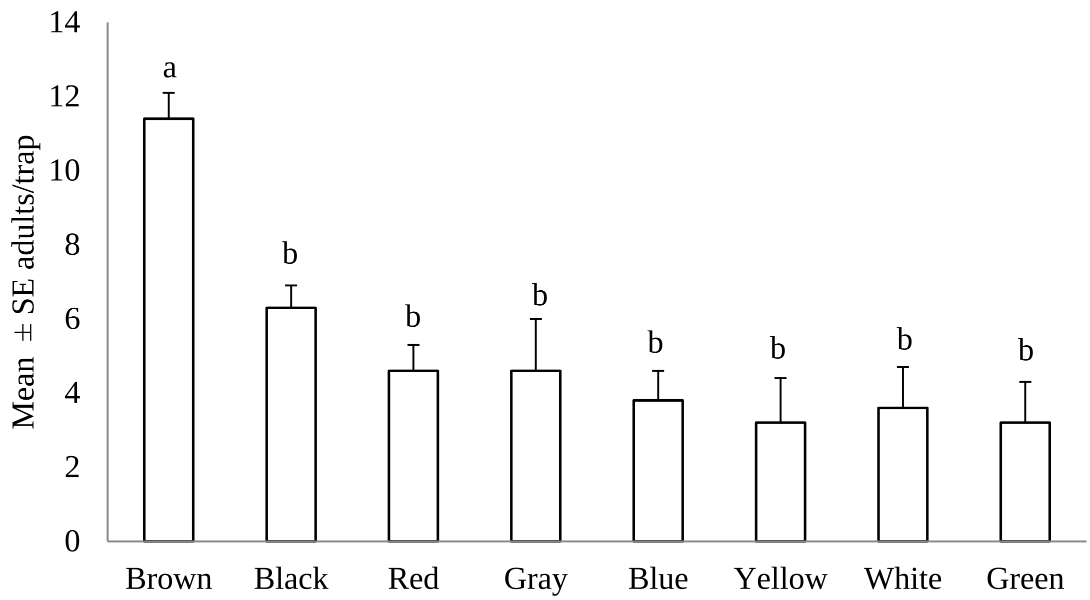

14
12
10
8
6
4
2
0
Mean ± SE adults/trap
a
b
b
b
b
b
b
b
Brown
Black
Red
Gray
Blue
Yellow
White
Green

Figure 5

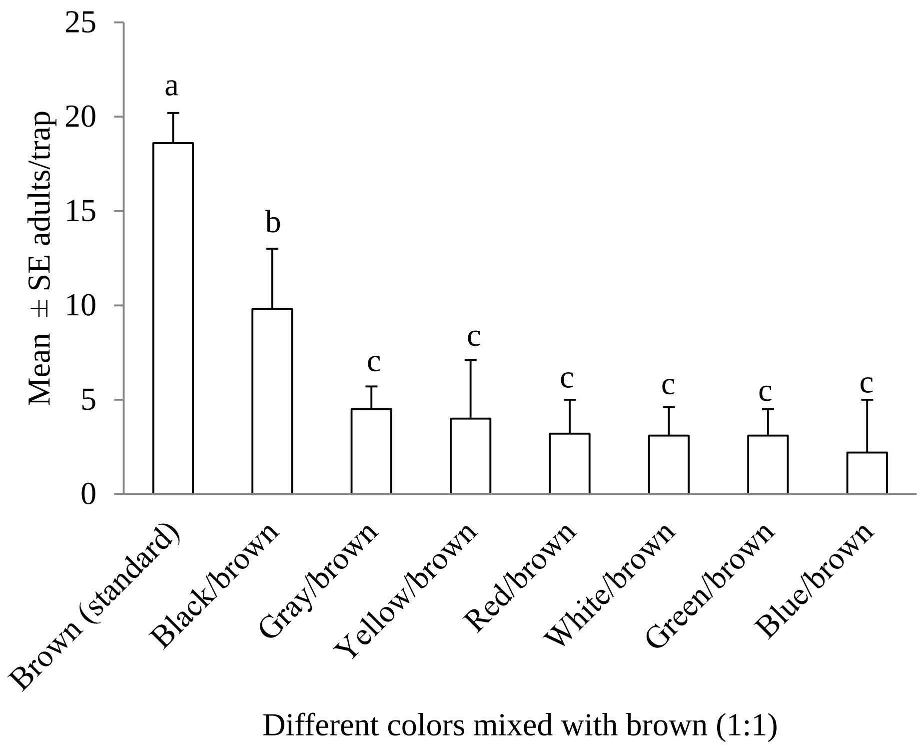
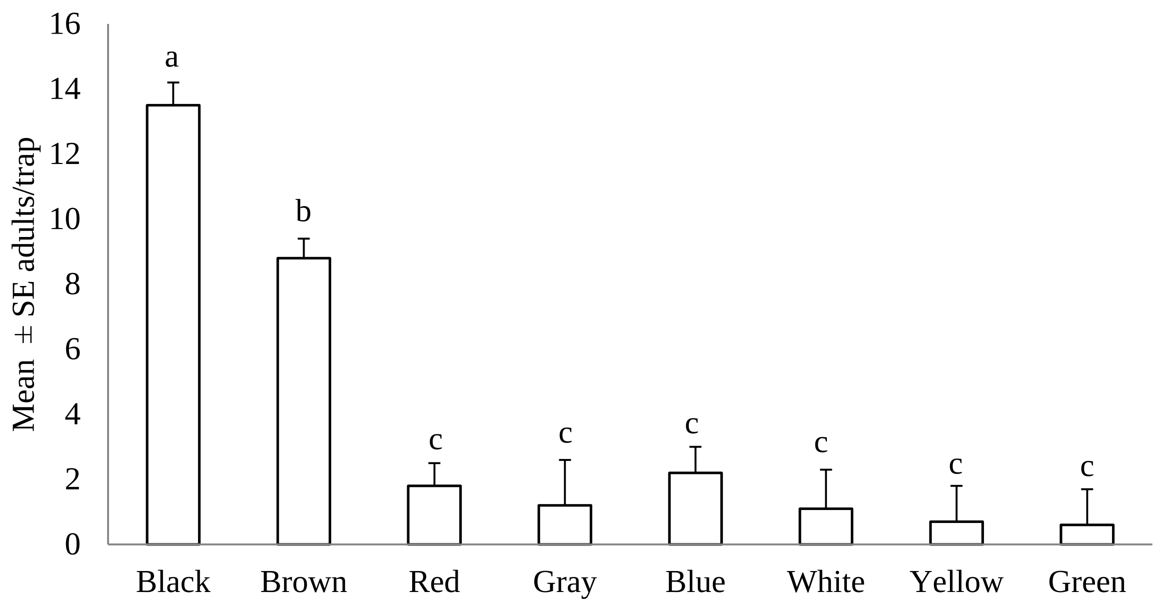

25
20
15
10
5
0
Mean ± SE adults/trap
a
b
c
c
c
c
c
c
Brown (standard)
Black/brown
Gray/brown
Yellow/brown
Red/brown
White/brown
Green/brown
Blue/brown
Different colors mixed with brown (1:1)

Figure 6



16
14
12
10
8
6
4
2
0
Mean ± SE adults/trap
a
b
c
c
c
c
c
c
Black
Brown
Red
Gray
Blue
White
Yellow
Green

Figure 7

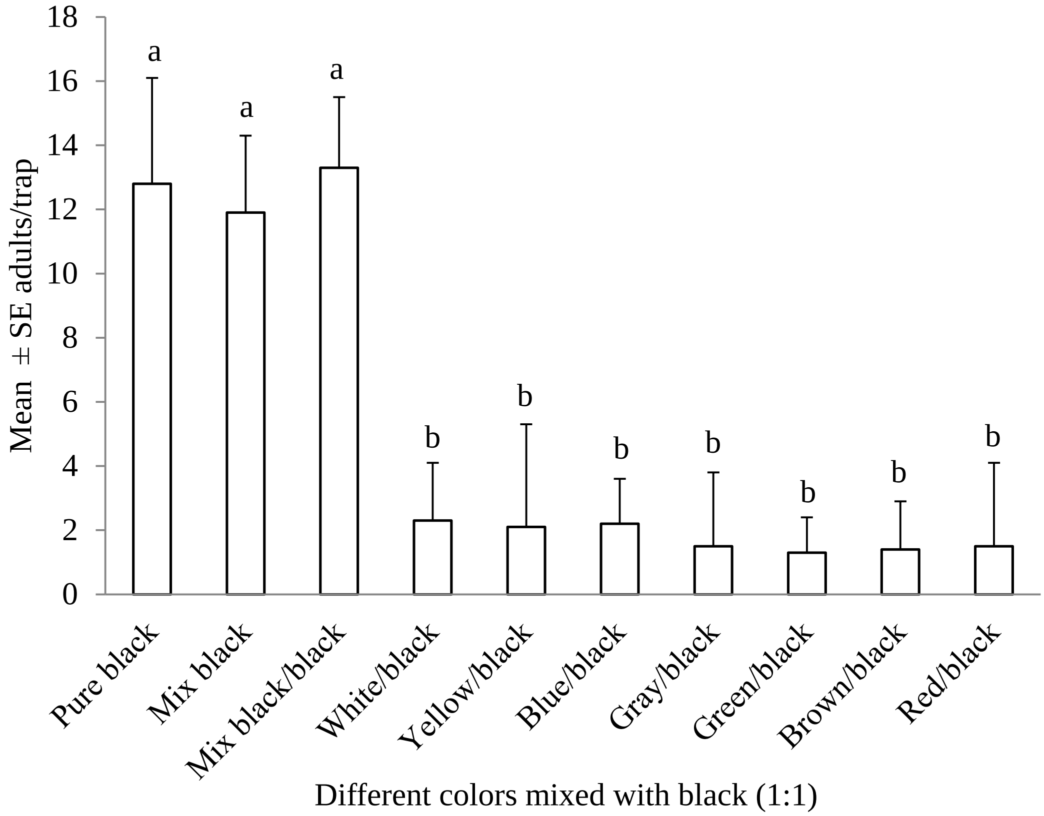
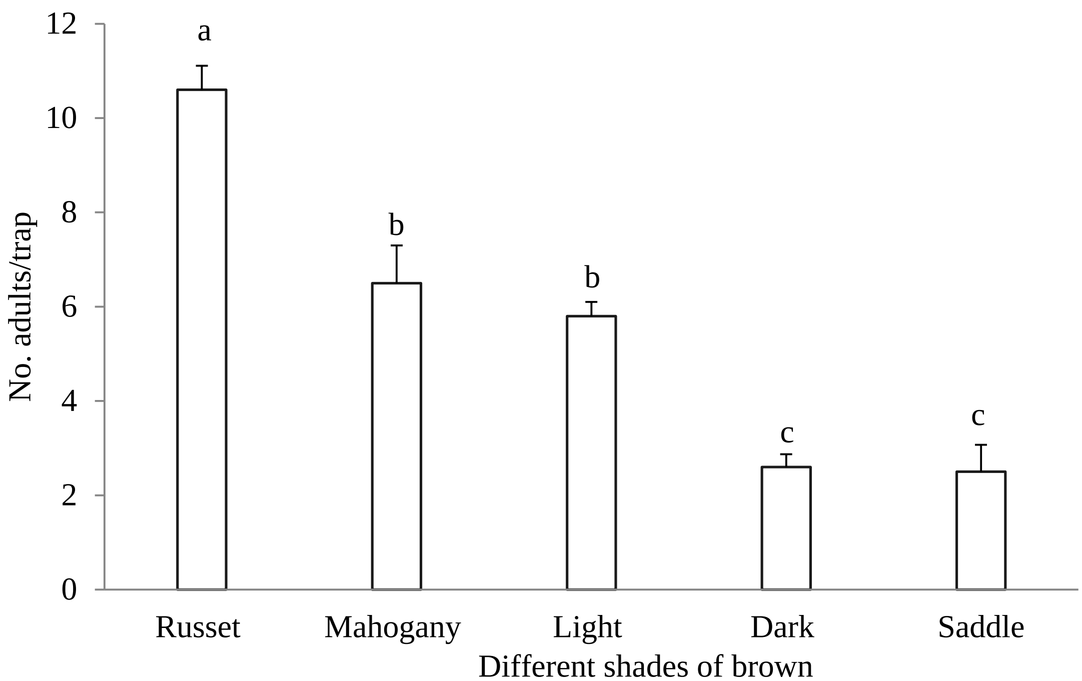

18
16
14
12
10
8
6
4
2
0
Mean ± SE adults/trap
a
a
a
b
b
b
b
b
b
b
Pure black
Mix black
Mix black/black
White/black
Yellow/black
Blue/black
Gray/black
Green/black
Brown/black
Red/black
Different colors mixed with black (1:1)

Figure 8



No. adults/trap
0
2
4
6
8
10
12
a
b
b
c
c
Russet
Mahogany
Light
Dark
Saddle
Different shades of brown

Figure 9

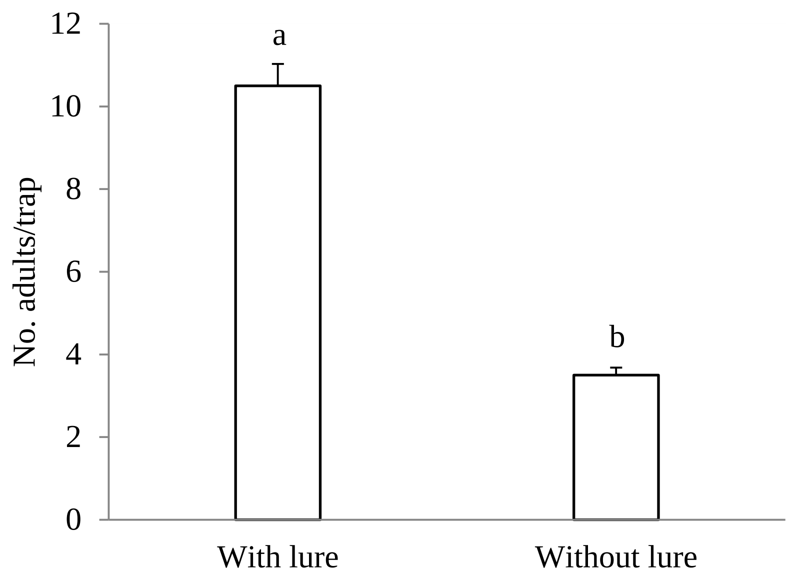


Figure 10

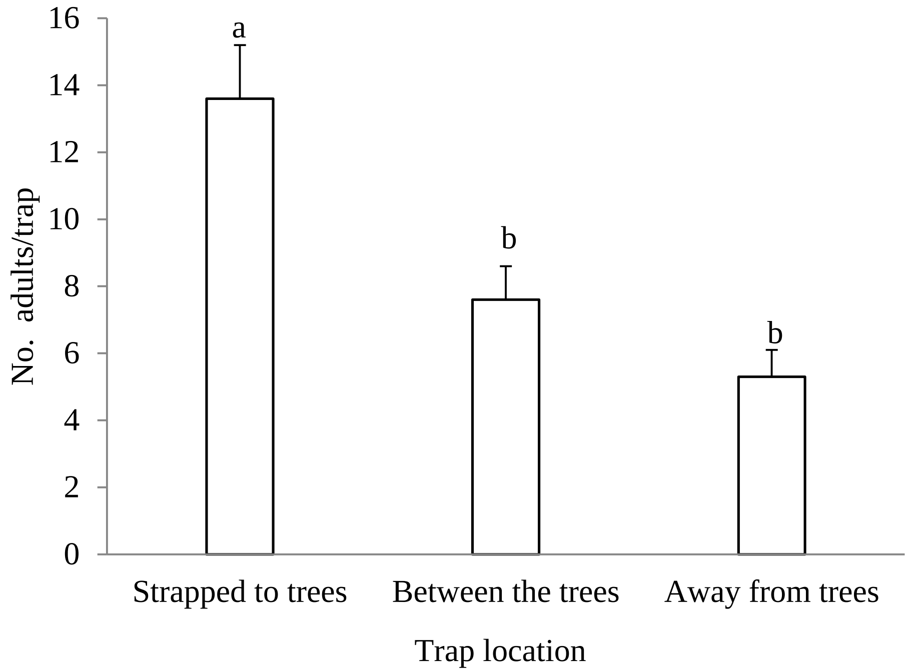

16
14
12
10
8
6
4
2
0
No. adults/trap
a
b
b
Strapped to trees
Between the trees
Away from trees
Trap location

Table 1 Color measurements of traps used in the present study[a]

Trap color	L^*	a^*	b^*	Chroma (C)	Hue angle (h°)
Black	30.44 ± 0.06	0.42 ± 0.03	–1.08 ± 0.04	1.16 ± 0.05	—
Brown	35.26 ± 0.18	3.98 ± 0.03	3.94 ± 0.02	5.60 ± 0.03	44.66 ± 0.11
Gray	39.83 ± 0.11	-0.17 ± 0.02	–2.23 ± 0.01	2.24 ± 0.01	85.64 ± 0.47
Yellow	82.57 ± 0.02	-2.92 ± 0.03	84.02 ± 0.27	84.07± 0.27	91.99 ± 0.02
Red	42.84 ± 0.11	49.88 ± 0.28	19.44 ± 0.20	53.54±0.34	21.29 ± 0.09
White	92.29 ± 0.03	1.34 ± 0.01	–2.59 ± 0.04	2.91 ± 0.03	—
Green	43.50 ± 0.08	–27.32± 0.03	1.72 ± 0.09	27.37 ±0.03	176.39 ± 0.19
Blue	36.02 ± 0.10	15.19 ± 0.10	–35.82±0.12	38.91± 0.14	292.98 ± 0.08

[a]Means (± SD) were generated from three observations.

L* indicates the lightness of the color; and it runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black.

The a* axis, which runs left to right on the color chart, indicates a red shade when greater than zero (positive) and a green shade when less than zero (negative). Similarly, the b* axis, which runs vertically through the color chart, indicates a yellow shade when positive and a blue shade when negative.

Table 2 Color measurements of paint colors mixed with brown (1:1) used on ground traps[a]

Trap color	L^*	a^*	b^*	Chroma (C)	Hue angle (h°)
Gray/Brown	53.01 ± 0.02	8.59 ± 0.20	5.44 ± 0.06	10.16 ± 0.20	32.36 ± 0.32
Yellow/Brown	45.90 ± 0.46	4.17 ± 0.34	19.81 ± 0.26	20.25 ± 0.32	78.12 ± 0.80
Red/Brown	39.11 ± 0.11	22.40 ± 0.25	11.19 ± 0.07	25.04 ± 0.25	26.55 ± 0.12
White/Brown	67.07 ± 0.07	10.22 ± 0.02	5.95 ± 0.03	11.83 ± 0.03	30.21 ± 0.07
Green/Brown	36.23 ± 2.69	–7.12 ± 0.05	4.83 ± 0.04	8.61 ± 0.06	-
Blue/Brown	34.11 ± 0.06	–1.09 ± 0.03	–1.45 ± 0.01	1.81 ± 0.01	53.07 ± 0.82

[a]Means (± SD) were generated from three observations. Column headings are as in Table 1.

Table 3 Color measurements of paint colors mixed with pure black (1:1) used on ground traps[a]

Trap color	L^*	a^*	b^*	Chroma (C)	Hue angle (h°)
Red/Black	33.80 ± 0.02	1.75 ± 0.01	2.45 ± 0.02	3.01 ± 0.01	54.42 ± 0.40
White/Black	49.21 ± 0.05	-1.04 ± 0.01	-1.82 ± 0.01	2.10 ± 0.01	60.38 ± 0.12
Yellow/Black	34.60 ± 0.10	-2.61 ± 0.02	3.19 ± 0.05	4.12 ± 0.04	-
Blue/Black	31.67 ± 0.48	-0.19 ± 0.02	0.66 ± 0.03	0.68 ± 0.02	-
Gray/Black	38.67 ± 0.12	-0.49 ± 0.02	–1.02 ± 0.03	1.13 ± 0.02	64.48 ± 1.24
Green/Black	33.09 ± 0.13	-0.92 ± 0.01	0.77 ± 0.04	1.20 ± 0.03	-
Mix black/Black	32.48 ± 0.05	-0.16 ± 0.02	0.81 ± 0.04	0.82 ± 0.04	-
Brown/Black	33.41 ± 0.14	-0.36 ± 0.02	1.10 ± 0.02	1.15 ± 0.02	-
Pure Black	32.75 ± 0.24	-0.18 ± 0.03	0.72 ± 0.03	0.74 ± 0.02	-
Mix Black	31.89 ± 0.03	-0.12 ± 0.02	0.95 ± 0.02	0.96 ± 0.02	-

[a]Means (± SD) were generated from three observations. Column headings are as in Table 1.

Table 4 Color measurements of the different shades of brown[a]

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Dark brown	35.26 ± 0.18	3.98 ± 0.03	3.94 ± 0.02	5.60 ± 0.03	44.66 ± 0.06
Mahogany brown	35.91 ± 0.01	5.44 ± 0.02	4.35 ± 0.03	6.97 ± 0.03	38.65 ± 0.13
Russet brown	38.99 ± 0.03	11.37 ± 0.05	9.00 ± 0.01	14.51 ± 0.03	38.37 ± 0.07
Saddle brown	48.37 ± 0.01	9.25 ± 0.06	20.62 ± 0.02	22.60 ± 0.03	65.83 ± 0.10
Light brown	61.13 ± 0.03	4.50 ± 0.02	21.87 ± 0.02	22.33 ± 0.01	78.38 ± 0.03

[a]Means (± SD) were generated from three observations. Column headings are as in Table 1.

Table 5 Color measurements of the different shades of black[a]

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Pure black	32.75 ± 0.24	–0.18 ± 0.03	0.72 ± 0.03	0.74 ± 0.02	-
Mix black	31.89 ± 0.03	–0.12 ± 0.02	0.95 ± 0.02	0.96 ± 0.02	-
Black medium	30.44 ± 0.06	0.42 ± 0.03	–1.08 ± 0.04	1.16 ± 0.05	-
Black thick	33.8 ± 0.1	7.6 ± 0.2	–5.4 ± 0.1	9.28 ± 0.1	-

[a]Means (± SD) were generated from three observations. Column headings are as in Table 1.