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Development of Food-Luring Baited Traps for *Solenopsis invicta* (Hymenoptera: Formicidae) Monitoring in the Field in Southern China

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Abstract

Solenopsis invicta Buren (Hymenoptera: Formicidae), a red imported fire ant that originated from South America, is a worldwide invasive pest. This study investigated the efficacy of the newly designed baited trap to detect red imported fire ants, *Solenopsis invicta* Buren, under field conditions in China. Among the five food lures tested for red imported fire ants, the ants preferred ham sausage and fish powder, followed by mixed powder (50% fish powder + 50% black soldier fly powder) and black soldier fly powder. These lures were compared to sugar water (control) to determine their efficacy in trapping red imported fire ants. Field data revealed that the ham sausage powder trap was more efficient than the fish powder trap based on its ability to trap more red imported fire ants under field conditions and ease of use. Thus, it was concluded that the baited traps are efficient for long-term red imported fire ants monitoring.

Introduction

The red imported fire ant (RIFA), *Solenopsis invicta* Buren (Hymenoptera: Formicidae), native to South America, was accidentally introduced into the southern United States in the 1930s. This alien species has since been an invasive pest, threatening agriculture, local biodiversity, and public health (Williams et al., 2001). This devastating invasive pest was detected in Hong Kong and mainland China in 2004, Mexico in 2005 (Sánchez-Peña et al., 2005), Taiwan in 2003 (Chen et al., 2006), and Australia in 2001 (Henshaw et al., 2005). Based upon the model described by Morrison et al. (2004) and Morrison et al. (2005), many areas worldwide, including large portions of Europe, Asia, Africa, Australia, and numerous island nations, are at risk for RIFA introduction. The *S. invicta* that arrived in Taiwan came from the USA (Yang et al., 2008). Until the end of 2009, this invasive species had infested more than 48,000 ha of land in Taoyuan, Taipei, and Jayi counties, Taiwan. Due to its aggressiveness and dominant behavior, several local ant species have already been displaced from their habitat in Taiwan (Tsai et al., 2009).

Baiting is the most efficient tool for controlling RIFA in large areas, and several attempts have been made to develop efficient baits (Chen, 2007; Kafle et al., 2009a; Vogt et al., 2003). After applying bait in the field, scheduled monitoring could elucidate that particular bait's efficacy for RIFA.

Therefore, a reliable and efficient monitoring tool is needed to determine the exact RIFA control efficacy under field conditions.

Generally, RIFA foragers use an extensive foraging tunnel system 20 -70 mm below the soil surface. The exit holes of these tunnels are distributed throughout their foraging territory, such that the foragers need to travel only a short distance, approximately 0.5 m, above ground to reach any point in their territory while foraging (Kafle et al., 2009b; Porter & Tschinkel, 1987). Therefore, ants walking in the tunnels escape the traditional monitoring tools researchers use (Oi et al., 2008; Tsai et al., 2009), such as pitfall traps or potato chips and hotdogs placed on the ground to monitor RIFA in the field. Furthermore, South China's highly humid and rainy weather affects the efficacy of the traditional pitfall trap. There is a lack of a thorough and standardized process for preparing bait attractants, and most research is focused on developing bait and trap devices. We hypothesized that the bait attractants could attract surface-walking ants and those moving through tunnels below the ground. Therefore, this study aimed to determine RIFA's most preferred food lure under field conditions for monitoring in southern China.

Materials and Methods

Source of Solenopsis invicta

S. invicta natural colonies were selected from the lemon garden in the suburb of Zengcheng, Guangdong Province Zengcheng, Guangdong Province, China, with ambient conditions [25 ± 2 ºC and 55 ± 5% relative humidity (RH)] and 14h :10h (light: dark) photophase conditions.

Foraging area

S. invicta chose a foraging location between 0.5 and 1.5 meters from the ant nests' entrance. With shovels, branch shears, and other supplies, the *S. invicta* nest was cleared out, and a platform about 15 cm broad was ignited and smoothed around the *S. invicta* nest (Figure 1). During treatment, turbulence to ant nests should be reduced; further studies were conducted (wait for 10-15 minutes) once the *S. invicta* has returned to the nest due to the turbulence.

Food-lure and placement

Food lures prepared for evaluation (approximately 2g) were kept on the plastic Petri dish and placed at equidistant locations along the inner wall of the circular foraging area. The food lures – fish powder (FP), black soldier fly powder (BSFP), mix powder (50% fish powder + 50% black soldier fly powder)(MP), ham sausage (HS), and sugar water (as control) – used during this study were obtained from a local market.

As illustrated in Figure 2, 2g of various baits in a plastic Petri dish with a breach 1 cm wide was simultaneously put on a flat circular platform around the nest, with the breach pointing towards the center of the nest foundation. The bait's distances from the center of the nest base and between the Petri dishes were the same (around 5 cm).

In this study, we used an adequate amount of various bait in the plastic culture with a 1 cm-wide aperture, as illustrated in Figure 2. Then, simultaneously, an equal distance separated the bait and the center of the nest base; the Petri dish was placed on the flat annular platform surrounding the nest, with the opening facing the center of the nest base. The distance between the Petri dishes was equal (greater than or equal to 5 cm).

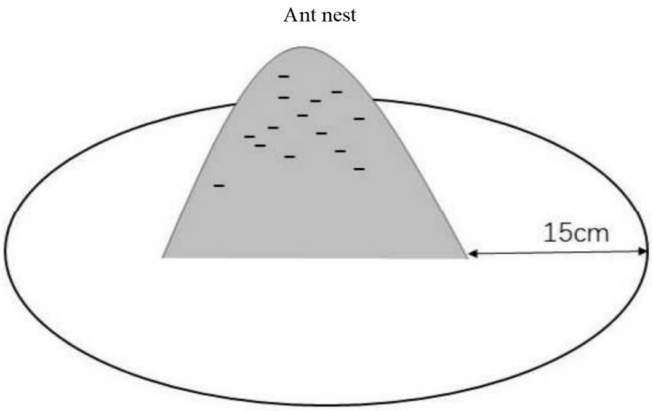

Fig 1. Simplified sketch of flat circular platform around red fire ant nest.

The bait and the control were put in a plastic petri dish with a side hole (Figure 2). Five Petri dishes with similar spacing (same spacing between neighboring Petri dishes and spacing 5 cm) were set simultaneously on a level circular platform around the ant nest. The placement impact and method is illustrated in Figure 3 and 4. There was an identical distance between each bait and the center of the ant nest's base. Throughout the investigation, field temperature, relative humidity, and wind speed were 26.2 ºC, 65.1%, and 60.5 km/h, respectively.

Data recording and analysis

High quality images were taken 5 minutes, 10 minutes, 20 minutes, and 40 minutes after the bait or bait preparation was placed, and the time required for the bait or bait preparation to be transported was recorded, with three replicates for each treatment.

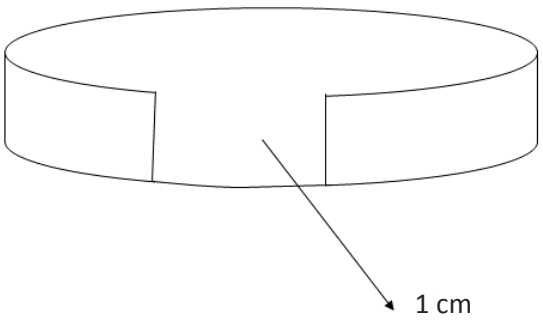

Fig 2. Simplified sketch of a Petri dish containing the bait (having a 1 cm wide gap in the sidewall).

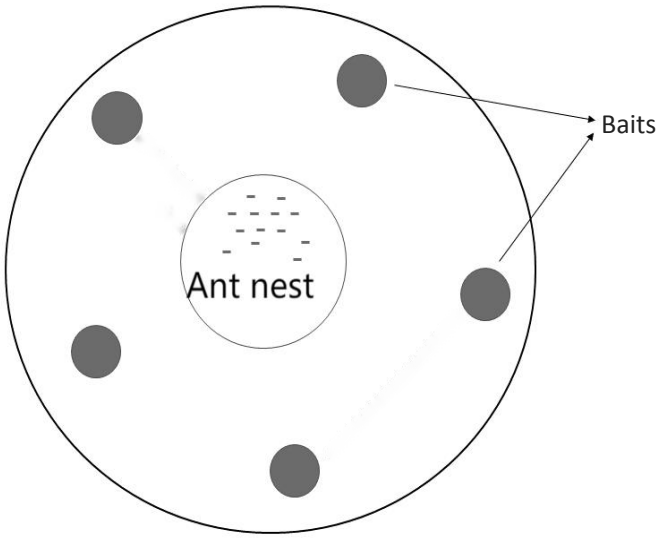

Fig 3. Simplified sketch of a red fire ant nest and baits (top view).

Four experimental ant nests were chosen at random and treated in the field. Each treatment's data was recorded. Data for each treatment were analyzed using Tukey's test (SAS Institute 2009) and analyzed using Excel and SPSS 19.0, and the luring effect of baits was evaluated.

Fig 4. Baits placement demonstration.

Results

Attraction effect of bait to the red imported fire ant

The results showed that the fish meal and the degreased insect powder were mixed to improve the attraction of the skimmer powder. According to the statistics of 5 minutes in Table 1, the best attraction effect of gammon sausage to red fire ants was discovered; the attraction of fish powder to red fire ants was better than that of skimmer insect powder.

Generally, red imported fire ants perceive ham sausage as the most alluring bait (Table 1). The effect of defatted insect powder was the worst; the fish powder was ranked second. The red fire ants' preference for defatted insect powder can be increased by mixing it with fish powder and degreasing it.

Except for the defatted insect powder, most of the other three treatments were delivered into the nest at 40 minutes (Table 1). Hence, the number of *Solenopsis invicta* during these treatments was lower than at 20 minutes. No pictures were taken 80 minutes ago because red imported fire ants were transporting fish powder bait, fish powder + defatted insect powder bait, and ham sausage.

Attraction effect of the preparation of bait on the red imported fire ant.

According to the statistical data in Table 2, at 5 min, the attraction effect of fish powder bait to red imported fire ants was significantly better than that of defatted insect powder. Fish powder and defatted insect powder were mixed to make bait, which significantly improved the attraction effect of defatted insect powder. Fishmeal baits have the best overall attraction effect on red imported fire ants among the three baits. The effect of defatted insect powder bait was the worst. The attraction effect of defatted insect powder bait mixed with fish meal on red imported fire ant was improved (Table 2).

At 40 min, most of the other three treatments were transported into the nest except defatted insect powder, so the number of red imported fire ants on these three treatments was less than that on 20 min. Fish powder bait, fish powder + defatted insect powder bait, and ham sausage were transported by red imported fire ant 80 minutes ago, so no photos were taken at 80 minutes.

Table 1. Field preferences of *Solenopsis invicta* workers for various food lures.

Food lures	No. of ants (mean ± standard error)*			
	5 min	10 min	20 min	40 min
Fish powder	64.33 ± 19.27 b	102.33 ± 31.13 b	164.0 ± 35.12 b	141.33 ± 18.11 b
Mix powder	50.0 ± 17.11 c	72.0 ± 15.13 c	81.67 ± 13.24 c	130.33 ± 18.08 c
Black soldier fly powder	10.67 ± 4.50 d	23.33 ± 12.03 d	32.0 ± 6.13 d	34.67 ± 11.48 d
Ham sausage	162.67 ± 28.45 a	260.67 ± 25.46 a	253.67 ± 36.21 a	105.0 ± 20.20 a
Sugar water	4.33 ± 4.02 e	5.67 ± 8.01 e	1.0 ± 1.41 e	3.67 ± 5.12 e

Food lures were arranged randomly (multiple free choices). *Means in the same row followed by the same letters were not significantly different ($P < 0.05$) using Tukey's test.

Table 2. Comparison of the time RIFA takes to carry the bait.

Food lure	Fish powder	Mix powder	Black soldier fly powder	Ham sausage	Control (sugar water)
Time (min)	58.67 ± 6.16 d	84.33 ± 10.20 c	120 ± 14.2 b	43.0 ± 4.46 e	140 ± 2.06 a

Discussion

Our study revealed that ham sausage was RIFA's most preferred food lure among the food lures tested. This was primarily due to RIFA's preference for protein-rich animal meals (unpublished data). RIFA favored BSFP over fish powder and mixed powder in the present study compared to the control (sugar water). However, BSFP was not as effective as fish powder or Mix powder, but it was still preferred to the other food lures (control)

It was clear from this study that when observation time increased from 5 to 40 minutes at each observation location, more RIFA were present because RIFA required time to recognize food lures. More foragers were seen toward the end of the observation period because RIFA solicited their nestmates to help them retrieve the food once it had been found. However, fish powder, Mix powder, and BSFP attracted more ants for a longer observation time and fewer ants for a shorter observation time, especially 30 to 40 minutes. We discovered that ham sausage was more effective for attracting RIFA at a short distance for a long time or a long distance for a shorter time. With time, more ants became attracted to the fish powder and ham sausage.

The number of RIFA gathered on the ham sausage at different times was significantly higher than the Fish powder, MP, and BSFP (Table 1), indicating that the ham sausage lure effect on the RIFA was significantly better than the MP and BSFP. However, when the ham sausage was incorporated into our experiment as a good bait for the RIFA in field investigation, we observed that the lure impact of the sausage was significantly higher than other baits (Table 1).

The RIFA required 43 min as the least time to transport the ham sausages (Table 2). However, due to the high cost of sausages, they cannot be used for the commercial production of RIFA bait compositions. At 40 minutes, the RIFA gathered on the sausage significantly decreased because the remaining amount of sausage was minor; similarly, the number of RIFA on the FP decreased (not significantly), and a portion of the RIFA turned to the MP (Table 1), indicating that the lure effect of BSFP on RIFA was minimal.

Conclusions

Our study showed that the ham sausage attracted surface-walking ants and was more effective than the other baits in the field. The standardized evaluation process we devised in this study for the enticing influence of RIFA baits applies to low nest density areas, and homogeneity and homogenization can ease nest selection problems when researchers do research in areas with such characteristics.

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Authors' Contribution

ZW: Conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing-original draft, Writing-review and editing, funding acquisition.
RM: Conceptualization, methodology, writing-original draft, Writing-review and editing, supervision, funding acquisition.
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MH: Conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing-original draft, Writing-review and editing, funding acquisition.
ZS: software, Writing-review and editing.
YY: software, Writing-review and editing.
BX: software, Writing-review and editing.
CH: data curation, Writing-review and editing.

All authors have read and agreed to the published version of the manuscript.

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