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Control of *Bradysia odoriphaga* (Diptera: Sciaridae) by soil solarization

Cai-hua Shi[a,b,1], Jing-rong Hu[a,1], Qi-wen Wei[c], Yu-ting Yang[a], Jia-xu Cheng[a], Hao-lin Han[b], Qing-jun Wu[b], Shao-li Wang[b], Bao-yun Xu[b], Qi Su[a], Chuan-ren Li[a], You-jun Zhang[b,*]

[a] College of Agriculture, Yangtze University, Jingzhou, 434025, Hubei, PR China
[b] Department of Plant Protection, Institute of Vegetables and Flowers, Chinese Academy of Agricultural Sciences, Beijing, 100081, PR China
[c] National Agricultural Technology Promotion Center, Beijing, 100081, PR China

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ABSTRACT

The subterranean insect *Bradysia odoriphaga* (Diptera: Sciaridae) is an important pest in China and is especially damaging to Chinese chive. This study determined the exposure temperatures and times required to kill various stages of *B. odoriphaga in vitro*, the optimal plastic film for soil solarization, and the effects of soil solarization on control of *B. odoriphaga*. *In vitro* mortality was 100% when adults, eggs, larvae, or pupae were exposed to a constant temperature of 40 °C for 1.3, 1.8, 2.8, or 3.7 h. Among four kinds of plastic film (white common plastic film, light blue anti-dropping film [LBADF], white anti-dropping film, and black-white film), soil temperature increased fastest and remained over 40 °C for the longest time with 0.12-mm-thick LBADF located 30 cm above the soil surface. Favorable soil solarization with 0.12-mm-thick LBADF located at 30 cm above the soil surface or on the soil surface just 1 d after treatment provided 100% control of *B. odoriphaga.* The growth of Chinese chive was slower in solarized plots than in control plots for about 10 days but subsequently was faster in the solarized plots. At 20 days after treatment, the differences in yields between solarized plots and control plots were not statistically significant. This is the first report that soil solarization can be used to control *B. odoriphaga* in Chinese chive fields. This approach needs to be investigated for management of other plant diseases and insect pests.

1. Introduction

Chinese chive (*Allium tuberosum* Rottler ex Sprengel) is an edible and medicinal plant that is widely grown in China, Vietnam, Thailand, Indonesia, Malaysia, and the Philippines (Imahori et al., 2004; Shi et al., 2016a). The major pest of Chinese chive, *Bradysia odoriphaga* Yang and Zhang (Diptera: Sciaridae) (Yang and Zhang, 1985), is common in China and has a wide host range that includes seven families and 30 plant species, such as garlic, welsh onion, cabbage, radish, melon, celery, flowers, mushrooms, and Chinese chive (Yang et al., 2015; Shi et al., 2017). *B. odoriphaga* is distributed in the soil layer at 0–5 cm (Shi et al., 2016b), and especially damages the rhizomes of Chinese chive (Zhang et al., 2015). In the absence of control the pest may destroy entire plants and cause up to 50% yield loss (Li et al., 2015).

In attempts to control *B. odoriphaga*, growers use several different techniques including modifying the cultivation pattern, as the damaging peaks of this pest are less in the field than in greenhouses (Dang et al., 2001); deploy black colored plates to a height of 20 cm aboveground (Wang et al., 2015); trap the adults with sweet and sour liquid (sugar: acetic acid: dehydrated alcohol: water = 3:3:1:80) (Wang et al., 2011); release entomopathogenic nematodes. For example, doses of *Heterorhabditis indica* LN2 strain of 400 IJs per larva gave a control efficacy of 88.2%, with an optimal environmental temperature of 25–30 °C, and soil water content of 10–15% (Sun et al., 2004). Each of these methods, however, has limitations including low efficacy and high cost, etc. *B. odoriphaga* is still a serious threat for Chinese chive production in China. Therefore, application of insecticides is still the most popular method to control *B. odoriphaga* (Li et al., 2014b). Toxic accidents frequently occur after eating Chinese chives in China. Therefore, an effective, inexpensive and environmentally safe method is needed to control *B. odoriphaga* on Chinese chive.

High temperatures can reduce the fitness of pests and even kill them. For example, a treatment of 2 min at 52 °C killed 100% of *Cydia pomonella* Linnaeus (Lepidoptera: Tortricidae) larvae (Wang et al., 2004), and a treatment of 12 min at 60 °C killed 100% of *Tribolium*

* Corresponding author. Department of Plant Protection, Institute of Vegetables and Flowers, Chinese Academy of Agricultural Sciences, No. 12 Zhongguancun Nandajie, Haidian District, Beijing, 100081, PR China.

E-mail addresses: shicaihua1980@126.com (C.-h. Shi), zhangyoujun@caas.cn (Y.-j. Zhang).

[1] There authors contributed equally to this paper.

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confusum Duval (Coleoptera: Tenebrionidae) larvae (Boina and Subramanyam, 2004). According to our laboratory studies, the optimal temperature for *B. odoriphaga* growth ranges from 20 to 25 °C (Li et al., 2015); higher temperatures reduce *B. odoriphaga* survival (Cheng et al., 2017), and *B. odoriphaga* abundance in China is low in summer (Shi et al., 2016b). These previous findings suggest that *B. odoriphaga* might be controlled by increasing the soil temperature where *B. odoriphaga* occurs.

Soil temperatures can be rapidly increased by covering the soil surface with a clear plastic film and permitting sun exposure, i.e., by soil solarization (Stapleton, 2000). The rate at which the soil temperature increases, however, depends on the characteristics of the plastic film (Ramakrishna et al., 2006).

In the current study, we determined the exposure temperatures and times required to kill *B. odoriphaga in vitro*, and we determined which kind and thickness of plastic film caused the greatest increases in soil temperature. Using the optimal plastic film, we then compared the effect of soil solarization on soil temperature, growth of Chinese chive, and control of *B. odoriphaga* in the field.

2. Materials and methods

2.1. Plastic films

The following polyethylene films were purchased from Qingdao Taiguang Greenhouse Film Co., Ltd., Shangdong, China: white common plastic film (WCPF) with a thickness of 0.03 mm, 0.10 mm, 0.12 mm, and 0.14 mm; light blue anti-dropping film (LBADF) with a thickness of 0.08 mm, 0.10 mm, 0.12 mm, 0.14 mm, and 0.16 mm; white anti-dropping film (WADF) with a thickness of 0.10 mm and 0.12 mm; and black-white film (BWF) with a thickness of 0.14 mm.

2.2. *B. odoriphaga*

B. odoriphaga was collected from a Chinese chive field at the Yang Town farm in Shunyi (40°1′N, 116°6′E), Beijing, China, on 15 April 2016. Individuals were reared on Chinese chive rhizomes for three generations in an incubator (MLR-352H-PC) at 25 ± 1 °C, 70 ± 5% RH, and 14:10 (L:D). *B. odoriphaga* individuals were randomly collected by stage (eggs, larvae, pupae, and adults, all within the normal range of weight) and were used for the temperature tests described in the next section.

2.3. Effects of exposure temperatures and times on *B. odoriphaga* mortality *in vitro*

Groups of 50 non-sexed adults (eclosion within 8 h), 50 late-instar larvae (4th instar), 50 pupae (within 2 days), and 100 eggs (oviposition within 24 h) were placed in separate culture dishes (Φ = 6 cm) containing a 2-mm-thick layer of solidified agar. The culture dishes were placed in an incubator at one of six temperatures (36, 38, 40, 42, 44, or 46 °C) for one of 20 exposure times (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 24.0, or 48.0 h). Each combination of temperature and exposure time was represented by three replicate dishes. After the exposure, the culture dishes were maintained in an incubator at 25 ± 1 °C, 70 ± 5% RH, and 14:10 (L:D). Adults and larvae were counted as dead when they did not move if gently touched with a brush after 24 h at 25 °C. Pupae were counted as dead if they did not moult within 10 days at 25 °C. Eggs were regarded as dead if they did not hatch within 10 days at 25 °C.

2.4. Effects of plastic films on soil temperatures

Experiments were performed in July 2016 in a field at the Yang Town farm in Shunyi Area (40°1′N, 116°6′E), Beijing, China. The soil was a silt loam with 40% sand, 40% silt, 18% clay, and 2% organic matter. Plots of 4 m^2 (2 m × 2 m) were covered with one of the following plastic films: WCPF with a thickness of 0.03, 0.10, 0.12 and 0.14 mm; LBADF with a thickness of 0.08, 0.10, 0.12, 0.14 and 0.16 mm; WADF with a thickness of 0.10 and 0.12 mm; and BWF with a thickness of 0.14 mm. Each plastic film treatment was independently tested six times, i.e., on 6 sunny days on a different plot on each day, and then automatic temperature meters (ZigWSN-C-A, Beijing, China) were used to detect soil temperatures at 5 cm depth every 15 min for each sunny day. The probes of automatic temperature meters were the first inserted into 5 cm depth of soil, and then were covered the film. The probes were below the films. The maximum soil temperature and the length of time that the soil temperature exceeded 40 °C under different treatments were recorded. The limitation improved by the case of the instruments led to the experiment being performed on different days, the recorded data were compared with the recorded minimum value under different treatments on the same day, which were converted to increased proportion values for a better statistical analysis. The rate value between the highest soil temperature (*RST*) under different films on the same day was calculated by the formula $RST = \frac{ST}{STL}$ (*ST* are the highest soil temperature recorded under different treatments on the same day. *STL* is a minimum value among *ST*). Similarly, the rate value of the length of time for which the soil temperature exceeded 40 °C (*RT*) was calculated by the formula $RT = \frac{DS}{DSL}$ (*DS* is the duration on soil temperature over 40 °C among different treatments on the same day. *DSL* is a minimum value among *DS* except zero). If *DS* was equal to zero, *RT* would also be zero.

2.5. Soil temperatures as affected by sunlight intensity and the location of the plastic film (0.12-mm-thick LBADF) above the soil surface

Experiments were carried out from July to August 2016 in a field at the Yang Town farm in Shunyi Area (40°1′N, 116°6′E), Beijing, China. Chinese chive plants were cut before the experiments. The top and lateral surfaces of box-like frames were covered with 0.12-mm-thick LBADF, which was determined to cause the greatest increase in soil temperatures. Each frame was 7 m long and 3 m wide, but the distance from the top of the frame to the soil (DTSs) were 0.0, 0.3, 0.6, 0.9, 1.2, or 1.5 m, respectively. Soil temperature at 5 cm depth was measured with automatic temperature meters (ZigWSN-C-A, Beijing, China), and sunlight intensity at the soil surface without interference by plastic film was measured with an automatic sunlight meter (ZigWSN-C-S, Beijing, China). Measurements were recorded over 18 consecutive days. The maximum soil temperatures and the time that soil temperatures exceeded 40 °C were recorded. Each treatment (height of the top of the frame from the soil surface) was represented by one frame.

2.6. Control of *B. odoriphaga* via soil solarization with 0.12-mm-thick LBADF

In April 2012, Chinese chive seeds (cv. Pingjiu No. 1) were sown in an open field at the Department of Plant Protection, Institute of Vegetables and Flowers, Chinese Academy of Agricultural Sciences. In July 2012, the seedlings were transplanted into the field at the Yang Town farm in Shunyi Area, Beijing, China, at a rate of 5,000,000 seedlings per ha with a row spacing of 0.20 m. The plants were maintained according to recommended agronomic practices.

An experiment was conducted from May to September 2016, in the field described in the previous paragraph. The Chinese chive leaves were cut before the experiment began. Frames covered with 0.12-mm-thick LBADF were constructed as described in section 2.5; DTSs were 0.0, 0.3, 0.6, or 0.9 m, respectively. The plastic film was in place from 8:00 a.m. to 18:00 p.m. on the same day. Plots without plastic film were used as a negative control. For the positive control, plots without plastic were treated with a commercial formulation of the insecticide phoxim (40% EC at 1 L/667 m^2). The number of *B. odoriphaga* larva in each plot