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Comparing efficacy of insecticides against cabbage maggot (Diptera: Anthomyiidae) in the laboratory

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ABSTRACT

The efficacy of 29 insecticides was determined against cabbage maggot, *Delia radicum* (L.) through a laboratory bioassay by exposing field collected *D. radicum* maggots to insecticide-treated soil immediately after application. In an assay, 10 *D. radicum* maggots were exposed to insecticide treated soil and then efficacy of insecticides was determined using three parameters: (1) proportion of maggots on the soil surface after 24 h, (2) proportion of change in weight of turnip bait, and (3) dead maggots after 72 h. Efficacy index (scale of 0–100) was developed based on the three parameters. Efficacy index of 11 insecticides was ≥70 against *D. radicum* and they were zeta-cypermethrin, tolfenpyrad, fenpropathrin, clothianidin, bifenthrin, lambda-cyhalothrin, chlorpyrifos, ethoprop, thiamethoxam + lambda-cyhalothrin, pyrethrins, and oxamyl in the order of highest to lowest efficacy. There was a significant positive correlation ($R^2 > 0.5$) among the three parameters. Furthermore, persistence of efficacy was examined on eight insecticides, where *D. radicum* maggots were exposed to field aged (1, 3, 7, 14, and 30 d) insecticide treated soil. Percentages of *D. radicum* maggots dead and on the soil surface were significantly greater when field aged soil was treated with bifenthrin, tolfenpyrad and clothianidin than other insecticides for most of the field age interval treatments. Efficacy of clothianidin did not change through field age interval treatments. The implications of these results on *D. radicum* management in the central coast of California are discussed.

1. Introduction

Cabbage maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae) is an important insect pest of Brassicaceous crops worldwide (Coaker and Finch, 1971). The pest causes serious economic losses to broccoli (*Brassica oleracea* var. *italica* Plenck), cauliflower (*B. oleracea* L. var. *botrytis*), cabbage (*B. oleracea* L. var. *capitata*), broccoli raab (*Brassica rapa* L. subspecies *rapa*), Brussels sprouts (*B. oleracea* L. var. *gemmifera*), and turnip (*B. rapa* var. *rapa* L.) in the central coast of California, United States of America (USA). The value of Brassicaceous crops was estimated at ~$1 billion USD in 2013 (U.S. Department Agriculture, NASS, 2013). In Monterey County (USA), Brassicaceous crops in California are valued at ~$485 million USD and are grown in >34,390 ha (Monterey County Crop report, 2013).

In California's central coast, *Brassica* crops are grown throughout the year; as a result *D. radicum* problems persist year long (Joseph and Martinez, 2014). In other *brassica* growing regions, *D. radicum* pupae undergo diapause during the winter months, which enabled researchers to determine accurate emergence of adult flies in the spring and subsequent generations (Walgenbach et al., 1993; Jyoti et al., 2003; Dreves et al., 2006). Because typical winters in California's central coast are mild (ave. low temperature: >2.8 °C in the last five years) (US Climate data 2015), *D. radicum* rarely goes into diapause (Johnsen and Gutierrez, 1997); it is presumed that *D. radicum* populations remain active on the roots of *Brassica* crops and weed plants through the winter months (January to March). Similarly, average high temperatures during the summer months in the central coast persist in a cool range (~21 ± 5 °C) (Griffin and White, 1955; US Climate data, 2015). This suggests that *D. radicum* populations are less likely to aestivate in the summer.

D. radicum eggs are primarily laid in the soil around the crown area of the plant. A single female can lay 300 eggs under laboratory conditions (Finch, 1974). The eggs hatch in 2–3 days and the apodous maggots feed on the taproot for up to three weeks and can destroy the root system of the plant. The maggots pupate in the soil surrounding the root system and emerge into flies within 2–4

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weeks (Harris and Svec, 1966). Severe *D. radicum* feeding injury to the roots cause yellowing, stunting even plant death (Natwick, 2009).

Control of *D. radicum* on *Brassica* crops primarily involves the use of soil applied organophosphate insecticides such as chlorpyrifos and diazinon (Natwick, 2009). However, the persistent use of organophosphate insecticides has resulted in high concentrations of the insecticide residues in the water bodies (Hunt et al., 2003) posing risks to non-target organisms and public health through contaminated water. Currently, use of organophosphate insecticides is strictly regulated by California Department of Pesticide Regulation (California Environmental Protection Agency [CEPA], 2013) leaving growers with no clear options to combat *D. radicum* problems in *Brassica*. There is therefore an urgent need to determine the efficacy of alternate insecticides for *D. radicum* control.

Recent research results show that incidence of *D. radicum* infestation in direct seeded broccoli could be severe throughout the growing period except the first 30 d after sowing (Joseph and Martinez, 2014). This suggests that the alternate insecticides applied at sowing should not only be effective against *D. radicum*, but also provide a reasonable level of persistence of efficacy. Research has shown that *D. radicum* infestation can be suppressed by using organophosphate insecticides, particularly chlorpyrifos, for more than a month after planting because product residues persist for an extended period (Getzin, 1985; Chapman and Chapnan, 1986). However, it is not clear if the residues of alternate insecticides could persist and provide extended *D. radicum* control. As a result, growers and pest control advisers are currently using alternate insecticides to combat *D. radicum* without any research based information on their efficacy and level of persistence. Therefore, the objectives of the study were to (1) assess the relative efficacy of some alternate insecticides against *D. radicum* based on lethality, and ability to penetrate the insecticide treated soil and feed on the untreated bait, and (2) assess the persistence of efficacy of selected insecticides through lethality and ability to penetrate the treated field aged soil. Selection of insecticides was based on their efficacy and current usage in the central coast of California.

2. Materials and methods

2.1. Insect source

Cabbage maggots were collected from field grown broccoli plants in Chaular, CA. Infested broccoli roots were collected in plastic bins and transported to the entomology laboratory (University of California Cooperative Extension, Salinas, CA) where *Delia* spp. maggots were carefully extracted from the roots using forceps and brush. The maggots were randomly sampled and identified as *D. radicum* using Brooks (1951) key. The extracted *D. radicum* maggots were mostly second and third instars and were used in the bioassay. Because the first instar maggots were small sized and could easily be injured during extraction, they were not used in the bioassay. First instar larva has one median hook and a paired plate one either side of the cephalopharyngeal skeleton (Brooks, 1951). On second instar larva, the mouth hooks has two teeth whereas, those hooks are smooth on third instar larva (Coaker and Finch, 1971). Moreover, the first instar larvae are 1 mm or less in length whereas, the second and third instar larvae were more than 2–8 mm in length (Smith, 1927). The collected *D. radicum* maggots were temporarily stored in 60 by 15-mm polystyrene Petri dishes (Fisher Scientific, Pittsburgh, PA) lined with moist paper towel and the edges sealed with Parafilm® (Bemis Company, Inc. Oshkosh, WI) to reduce desiccation.

2.2. Bioassay

The bioassay was developed to determine the efficacy of insecticides against *D. radicum* larvae (second or third instar) because larval stages are the only destructive phase of *D. radicum* and are usually the target of insecticide applications. In addition to larval mortality, the ability of the maggot to penetrate the soil after being exposed to insecticide in the soil and the ability of *D. radicum* maggot to consume untreated *Brassica* root after exposure to insecticide treated soil were evaluated.

Typically, newly emerged *D. radicum* maggots travel through the soil to reach and infest the *brassica* roots. Insecticides targeting *D. radicum* control were therefore either applied at sowing as a narrow band along the seed line or at the base of the seedlings. This is to ensure that the *D. radicum* maggots come in contact with insecticide residues in soil as they attempt to travel through the soil layer before reaching the root system.

The bioassay consisted of translucent a polypropylene cup (6 cm diam. wide and 7.1 cm long), soil and turnip (*B. rapa* var. *rapa* L. variety 'Tokyo') bulbs, which were cut into thin 1–1.5 g cuboid slices (~0.3-cm [thickness] × 1-cm × 1-cm) and used as a bait. Untreated bait was placed in the center of the cup before soil was added. The Chualar loam soil (Clay, 44.8%; Sand, 14%; organic matter, 2.5%) was collected from a field in Chualar, CA where *D. radicum* infestation was persistent throughout the growing season. The soil was collected multiple times from the field for the study. Each time, ~1000 g of soil was dried in an oven at >100 °C for 72 h. Several preliminary bioassays were conducted to optimize the soil and water content suitable for *D. radicum*. Once optimized, twenty five grams (25 g) of the oven-dried soil was added to the cup burying the bait in the center-bottom, and 4.5 mL of insecticide solution per cup was uniformly pipetted on to the surface of the soil within the cup. Ten second or third instar maggots were put on the soil surface of each cup (experimental unit) then the cup was later covered with perforated caps to allow air flow. The cups were maintained at ~21 °C and ~45% relative humidity for 72 h before treatment evaluation.

2.3. Insecticide efficacy

Two experiments were conducted. The first experiment was conducted to determine the efficacy of the insecticides whereas, the second experiment was conducted to determine persistence of efficacy. In the first experiment, efficacy of 29 insecticides was tested against *D. radicum* maggots where larvae were introduced immediately after insecticide application (E_0). Distilled water was used as negative control. The details of insecticide, formulation, recommended rate and tested rates are presented in Table 1. Whenever possible, the insecticide recommended rates specifically for *D. radicum* or root maggot were used to determine the test rate. For insecticide products that lacked recommended rates, rates used for closely related insect pests of *Brassica* crops were selected for testing. The novel insecticides whose registration for use on *Brassica* or other crop category in the USA are still in progress or those that demonstrated effectiveness against *D. radicum* as soil applied insecticides in other agricultural systems were also included in the study. The rates of such new insecticides were determined after consultation with the manufacturer. Two insecticides, dinotefuran and tolfenpyrad were tested at maximum recommended rate (1.0×) as well as half rate (0.5×). The active ingredient bifenthrin was tested using two formulations, "Water Soluble Bag" (WSB) and "Liquid Fertilizer Ready" (LFR). Because the water volume generally varies between 280.6 and 560.7 L per ha in the central coast vegetable system when applied using tractor mounted sprayers, an intermediate water volume of 373.9 L per ha was selected for the