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Captures of *Protaphorura fimata* (Collembola: Poduromorpha: Onychiuridae) on Beet and Potato Baits in the Salinas Valley of California[1]

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Abstract *Protaphorura fimata* Gisin (Collembola: Poduromorpha: Onychiuridae) feeds on the germinating seeds of lettuce (*Lactuca sativa* L.), causing severe stand losses in the northern Salinas Valley of California. Because there is no grower-friendly tool available to monitor *P. fimata* in the commercial lettuce fields to guide management decisions, we examined the potential utility of potato slices (*Solanum tuberosum* L.), typically used to monitor garden symphylan, *Scutigerella immaculata* Newport, and beet slices (*Beta vulgaris* L.) as baits for *P. fimata* capture and compared them with *P. fimata* extracted from the soil using the Berlese funnel method. Results suggest that both potato and beet slices were attractive to *P. fimata* as they captured greater numbers of *P. fimata* when deployed in the soil than were extracted using a Berlese funnel. Between beet and potato, beet slices captured significantly greater numbers of *P. fimata* than potato slices in both years. In addition, two experiments were conducted to determine the effect of extended exposure of beet slices on *P. fimata* captures. Data suggest that greater numbers of *P. fimata* were captured with 1-d than 5-d exposure periods. However, there was no difference among 1- to 4-d exposures of beet in the soil.

Key Words springtail, *Lactuca sativa*, vegetable production, central coast

Recently, *Protaphorura fimata* Gisin (Family: Onychiuridae) was identified as a serious pest of lettuce (*Lactuca sativa* L.) in the northern Salinas Valley of California (Joseph et al. 2015). *Protaphorura fimata* is ~2.5 mm long and lacks pigmentation, furcula, and eyes (Fjellberg 1998). *Protaphorura fimata* primarily feeds on the radicle of the germinating lettuce seeds causing stunted seedling growth, and their high densities at planting is associated with poor lettuce stands (Joseph et al. 2015). Lettuce was valued at ~US$1.2 billion in Monterey County, California (Monterey County Crop Report 2013). *Protaphorura fimata* also feeds on germinating seeds of broccoli (*Brassica oleracea* var. *italica* Plenck).

Most springtails are saprophytic feeders considered as beneficial organisms because they aid in the decomposition of decaying plant material, thereby contributing to the cycling of carbon and nitrogen, which in turn improves soil health and structure (Coleman et al. 1983, Filser 2002, Hopkin 1997). Onychiurids, including *P. fimata*, are known as fungus feeders (Crist and Friese 1993, Jørgensen et al. 2003); however, a few onychiurid species have been reported as pests in

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commercial agriculture (Baker and Dunning 1975, Brown 1983, Boetel et al. 2001, Endlweber et al. 2009, Heijbroek et al. 1980, Hurej et al. 1992, Spencer and Stracener 1929, 1930). Recently, *P. fimata* was identified as a major pest of lettuce as they feed on the germinating seeds (Joseph et al. 2015).

Identifying an effective monitoring tool for *P. fimata* could be the first step toward developing a threshold-based decision system for use in the management of *P. fimata*. Although there are no specific insecticides recommended for use against *P. fimata* (Natwick 2009), growers use pyrethroid and neonicotinoid insecticides as a preventative spray; these insecticides are typically targeted to manage other soil-borne arthropods. Researchers use the Berlese funnel method or modified variants of the Berlese funnel, such as the Tullgren-type extractor, to detect springtails in the soil (Crossley and Blair 1991); both methods extract all soil arthropods present in the sampled soil. From a grower's standpoint, the Berlese funnel method would not only be cumbersome and laborious but also may not provide timely information for treatment decisions. Clearly, there is a need for a grower-friendly, *in situ* monitoring method to determine incidence and abundance of *P. fimata* in the lettuce fields of California's central coast. Garden symphylan, *Scutigerella immaculata* Newport, another soil-borne arthropod pest that occurs in vegetable fields, is commonly monitored using a potato slice (*Solanum tuberosum* L.) as bait (Umble and Fisher 2003, Umble et al. 2006, William 1996). Potato slices are typically deployed on the soil surface, and they attract soil arthropods including *S. immaculata*. The utility of potato slices for captures of *P. fimata* has not been investigated. Because potato slices are off-white in color, it might be difficult to quickly quantify lightly colored arthropods such as *P. fimata* and *S. immaculata* on the potato surface. Unlike potato slices, beets (*Beta vulgaris* L.) are dark red in color and may provide background contrast, which could help quantify lightly colored organisms on a slice. Moreover, total sugars in *B. vulgaris* root are 6.8 g per 100 g, which is seven times greater than in potato tuber (0.8 g per 100 g) (USDA ARS 2014). The major objective of this study was to determine the potential utility of potato and beet slices as baits to trap *P. fimata* in lettuce fields.

Materials and Methods

Trap types. The experiments were conducted in lettuce fields in the northern Salinas Valley of California from March to April 2014 and 2015. In both years, the treatments were arranged in randomized complete block design with 12 and 10 replications in 2014 and 2015, respectively. The three treatments were beet root (*B. vulgaris*) slices, potato (*S. tuberosum*) slices, and soil core samples. The treatments were 15.2 m apart within a block and blocks were separated by 2 m. The beet root and potato were purchased from local produce stores in Salinas, CA. Thin slices (~0.5 cm thick) of beet root ($\bar{x} \pm$ SE: 5.4 $\pm$ 0.09 cm diameter) and potato ($\bar{x} \pm$ SE: 6.0 $\pm$ 0.2 cm diameter) were cut in the field before deployment. These bait slices were placed in the subsurface of the soil about 5 cm deep (Fig. 1A, B) and covered with disposable white, 8.5-cm-diameter, 4-cm-deep plastic bowls (Hefty Consumer Products, Lake Forest, IL) (Fig. 1C). The *P. fimata* were collected from the undersides of the bait slices that were in contact with the soil. After 2 d, bait slices were removed, placed into plastic bags, and transported to the laboratory in

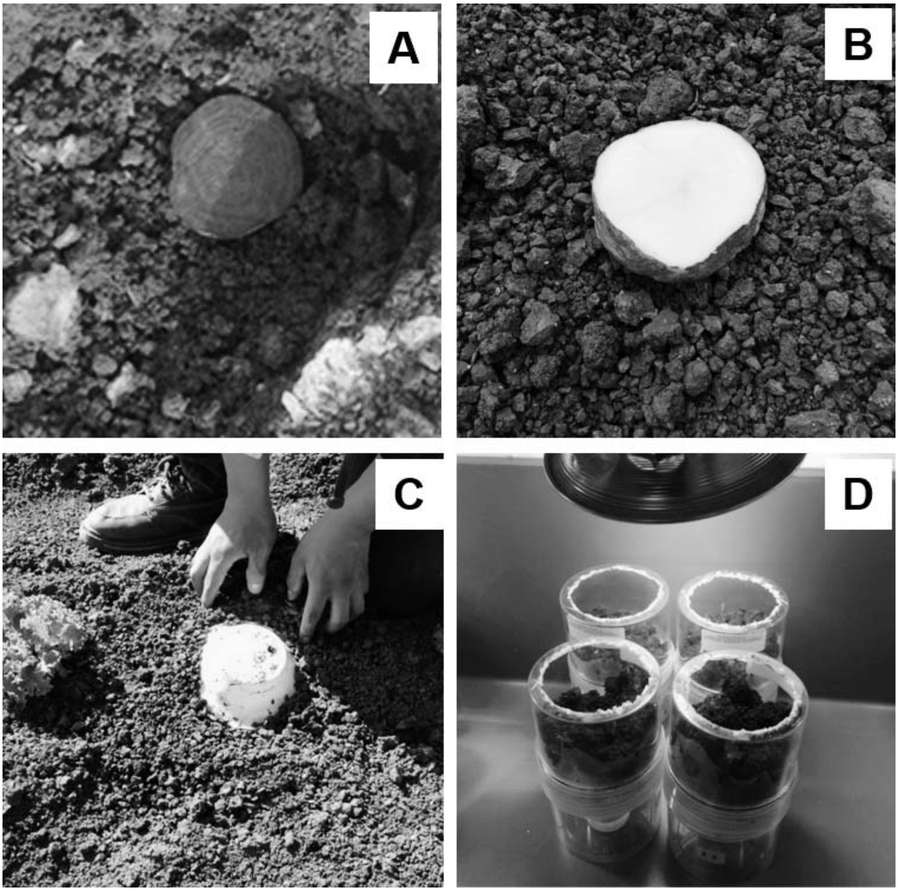

Fig. 1. *Protaphorura fimata* bait traps for (A) beet and (B) potato slice, (C) field deployment, and (D) Berlese funnel extracting *P. fimata* from the soil.

Salinas, CA. The captured *P. fimata* on the bait slices were quantified within 24 h using a dissecting microscope. Soil samples ($\bar{x} \pm$ SE: 310.2 $\pm$ 9.3 g) were collected using a 10.2-cm bulb planter from ~10-cm-deep subsoil at randomly assigned spots within the block on the day when the bait slices were removed for evaluation. The collected soil samples were transported to the laboratory and placed into modified 11.5-cm-diameter, 19.5-cm-tall small Berlese funnel traps (BioQuip, 2845, Rancho Dominguez, CA) for 7 d. Incandescent bulbs (25 W) placed over the funnels were used as light or heat sources and springtails were collected in 70% ethyl alcohol in a 100-ml plastic cup placed at the base of the funnel (Fig. 1D). The small Berlese funnel was modified by removing a 9-cm-diameter section from the top container to allow uninterrupted transmission of heat and light and prevent accumulation of water vapors within the ceiling of the top container. Three experiments were conducted each year. Bait and soil samples were collected on 28 February, and 4 and 12 March 2014, and 2, 4, and 5 February 2015 from the fields.

Length of deployment. In 2014, two experiments were conducted in two different lettuce fields. Because of the superior performance of beet in the preliminary experiments, beet root slices were used in these experiments. The beets were deployed in the soil as described in the previous section. The treatments were the exposure of beet slices for the following discrete time periods: 1, 2, 3, 4, and 5 d in the soil. These baits were removed on 5, 6, 7, 8, and 9 March 2014, and 14, 15, 16, 17, and 18 April 2014. The treatments were arranged in a randomized complete block design with 10 replications. The captured *P. fimata* were quantified within 24 h by examining the slices using a dissecting microscope.

The number of *P. fimata* collected from various trap types and days of exposure were square root–transformed to establish homogeneity of variance. Analysis of variance was performed on transformed data for each experiment using the PROC GLM procedure in SAS (Version 9.3, SAS Institute Inc., Cary, NC), and means were separated using the Tukey's honestly significant difference method ($P < 0.05$). The null hypothesis was that the variance was equal between *P. fimata* collected from trap types and exposure periods. Means and standard error for the variables were calculated using PROC MEANS procedure in SAS.

Results and Discussion

Trap types. Totals of 1,775 and 1,564 *P. fimata* were captured in all the trap types in 2014 and 2015, respectively. In 2014, the number of *P. fimata* was significantly greater on beet bait than on potato and in the Berlese funnel during Experiment 1 ($F = 5.5$; df = 2,22; $P = 0.011$), Experiment 2 ($F = 4.8$; df = 2,22; $P = 0.018$), Experiment 3 ($F = 25.2$; df = 2,22; $P < 0.001$), and in all the experiments combined ($F = 22.2$; df = 2,22; $P < 0.001$) (Fig. 2).

In 2015, in Experiment 1, significantly more *P. fimata* were collected on beet and potato slices than in the Berlese funnel method ($F = 95.8$; df = 2,8; $P < 0.001$) (Fig. 3). Similarly, in Experiment 2, the number of *P. fimata* was significantly greater in beet and potato than in the Berlese funnel ($F = 23.3$; df = 2,18; $P < 0.001$), whereas in Experiment 3, *P. fimata* densities found on beet were significantly greater than on potato and from soil cores in the Berlese funnel ($F = 14.6$; df = 2,18; $P < 0.001$). When all the 2015 experiments were combined, significantly greater numbers of *P. fimata* were found on beet than on potato with the number extracted by the Berlese funnel method being significantly less ($F = 111.4$; df = 2,18; $P < 0.001$).

Length of deployment. In Experiment 1, the numbers of *P. fimata* captured on beet were not significantly different among the different lengths of exposure periods ($F = 0.6$; df = 4,33; $P = 0.659$) (Table 1); however, *P. fimata* captures on beet were numerically greater in the 1-, 2-, 3-, and 4-d exposure periods than with a 5-d exposure. In Experiment 2, the numbers of *P. fimata* captured on beet were significantly different among different lengths of exposure periods ($F = 2.9$; df = 4,36; $P = 0.037$), where the number of *P. fimata* captured on the 1-d exposure was significantly greater than on the 5-d exposure (Table 1). There was no difference in *P. fimata* captures on beet during 1-, 2-, 3-, or 4-d exposure periods.

Currently, there is no monitoring tool developed for *P. fimata*. The results clearly suggest that beet and potato attracted *P. fimata* when placed in lettuce fields, and suggest that baits could be used to monitor *P. fimata* in commercial field settings.

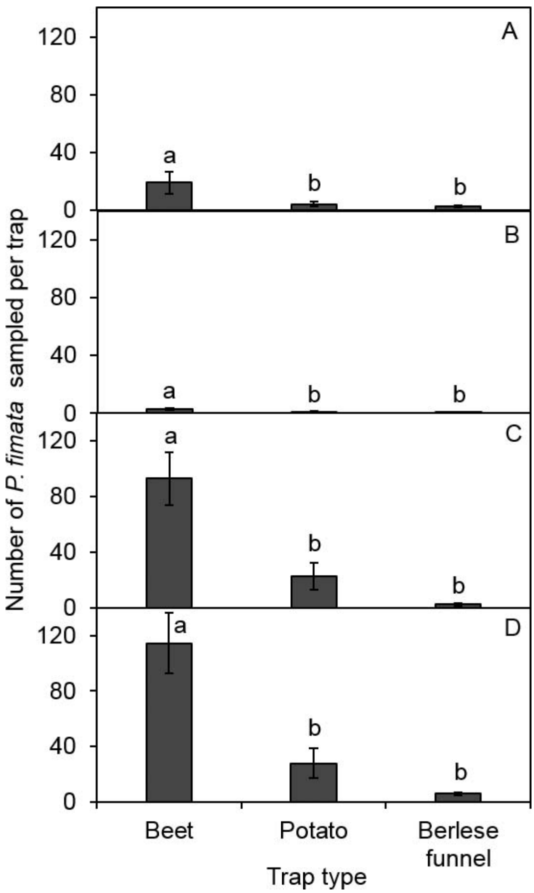

Fig. 2. Mean ± SE *Protaphorura fimata* captured on beet and potato baits and from soil in Berlese funnel in (A) Experiment 1, (B) Experiment 2, (C) Experiment 3, and (D) all experiments combined in 2014. Means with same lowercase letters among histograms are not significantly different (Tukey's honestly significant difference test, *P* > 0.05). Nontransformed data are presented.

Because a threshold has not been established using beet or potato to trigger treatment decisions, it could only provide the presence or absence information, which might be still important to avoid unnecessary insecticide application with no or low captures on baits.

There are benefits in using beet or potato slice baits as monitoring tool: (a) potato and beet baits can be locally grown or purchased from the local vegetable stores, (b) baits can be easily deployed in the field using plastic bowls, and (c) *P. fimata* trapped on the baits can be quickly assessed within a couple of days after deployment in the field. Capture of *P. fimata* on the baits suggests that *P. fimata* populations are likely developing in the upper soil profile especially near the root

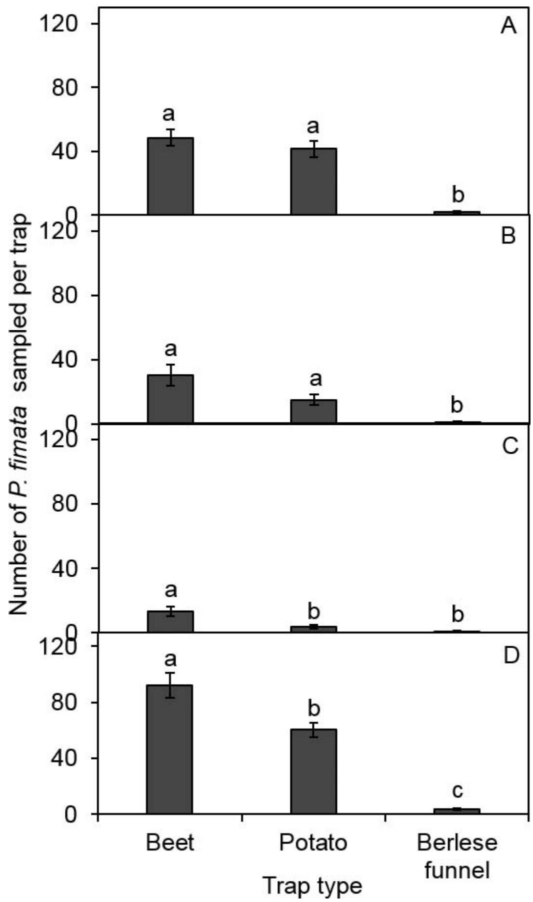

Fig. 3. Mean ± SE *Protaphorura fimata* captured on beet and potato baits and from soil in Berlese funnel in (A) Experiment 1, (B) Experiment 2, (C) Experiment 3, and (D) all experiments combined in 2015. Means followed by same lowercase letter among histograms are not significantly different (Tukey's honestly significant difference test, $P > 0.05$). Nontransformed data are presented.

system. Umble and Fisher (2003) indicated that potato slices provided a measure of actively foraging and feeding *S. immaculata* present in the upper soil profile. Also, the incidence and abundance of *P. fimata* is subjected to soil moisture and their captures likely decline sharply as the upper soil layer loses moisture (S.V.J. unpubl. data). The growers on the central coast of California irrigate the fields before the beds are shaped and once the seeds are planted, the beds are sprinkler-irrigated for at least 4–5 weeks. It is likely that *P. fimata* populations multiply as the preplant irrigation is initiated. Monitoring the field using baits before or during the initial irrigation may provide an indication of active *P. fimata* population in the upper soil

Table 1. Captures of *Protaphorura fimata* when subjected to various periods of time in the soil.

No. of Days of Beet-Bait Exposure	Mean ± SE *P. fimata* Captures	
	Experiment 1	Experiment 2
1	0.7 ± 0.3 a*	15.2 ± 5.5 a
2	0.9 ± 0.5 a	8.8 ± 5.5 ab
3	0.9 ± 0.5 a	9.5 ± 3.9 ab
4	0.3 ± 0.2 a	11.4 ± 3.6 ab
5	0.1 ± 0.1 a	0.7 ± 0.4 b

* Lowercase letters following means within a column are not significantly different (Tukey's honestly significant difference test, $P > 0.05$). Nontransformed data are presented.

profile. *Protaphorura fimata* problems and stand losses have been noted during the winter and early spring plantings in the northern Salinas Valley. Most of the rain events occur during these periods, which provide continuous supply of moisture to even uncultivated fields, aiding *P. fimata* population growth. Also, results suggest that greater numbers of *P. fimata* were collected on beet 1 d after deployment than after extended days of exposure. Perhaps deployment of baits for extended periods of time in soil may cause desiccation and make them less attractive to *P. fimata*.

In conclusion, data clearly suggest that beet and potato can attract *P. fimata* in the soil and could be used for monitoring *P. fimata* rather than sampling soil then extracting *P. fimata* using the Berlese funnel method. It is likely that baits are attracting *P. fimata* from the surrounding soil, although the active radius of attraction is not yet clear. The beet bait captured significantly more *P. fimata* than the potato bait. Moreover, because beet has a dark background, it is likely to provide a sharp contrast and help quantify *P. fimata*, which has a white or off-white color. *Protaphorura fimata* are slow-moving on the bait surface, but they curl up when disturbed and are likely to fall off the bait surface. Future studies will focus on tactics that will help determine threshold density for treatment decisions.

Acknowledgments

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