IMPACT OF SLUG BAITS ON THE SURVIVAL OF *PHASMARHABDITIS* NEMATODES

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Introduction

Slugs are among the most damaging pests of grass and clover seed production in the Willamette Valley. Control measures are limited and focus heavily on the use of molluscicidal baits, but growers report considerable variation in the efficacy of the most widely used active ingredients (metaldehyde, iron phosphate, and sodium ferric EDTA) (Mc Donnell and Anderson, 2017). Biological control—the use of a pest's natural biological enemies to combat it in the field—offers a compelling option.

Nematode worms in the genus *Phasmarhabditis* are important natural enemies of slugs in many parts of the world. In fact, in Europe, a species called *Phasmarhabditis hermaphrodita* is currently being used as a commercially available biological control agent called Nemaslug to successfully manage slug pests in a wide range of crops (Rae et al., 2007). There is considerable interest from growers and industry for a similar product to be developed for the U.S. market, especially now that multiple *Phasmarhabditis* species have been discovered on the west coast, including in Oregon (Mc Donnell et al., 2018; Howe et al., 2020). Consequently, there is a need to determine whether current slug control strategies affect the survival of these nematodes so that an informed decision can be made on their potential in the Integrated Pest Management of slugs in vulnerable crops. Thus, the goal of this study was to investigate the impact of multiple slug bait products on the survival of the three candidate biological control agents *P. hermaphrodita, P. californica,* and *P. papillosa*.

Materials and Methods

Survival trials

Oregon-derived strains of *Phasmarhabditis hermaphrodita, P. californica,* and *P. papillosa* were maintained in the laboratory on standard nematode growth media (NGM) agar plates and fed bacteria that co-culture with the nematodes.

The impact of the most commonly used molluscicide active ingredients (metaldehyde, iron phosphate, and sodium ferric EDTA) on the survival of these species was assessed by sprinkling NGM agar plates with 25–28 mg of pulverized pellets, which equates to the recommended label rate. The following molluscicide treatments were used:

- Metaldehyde at 4% (Deadline M-Ps) and 7.5% (Durham Granules 7.5)
- Iron phosphate at 1% (GardenSafe) and 3% (IronWorxx)
- Sodium ferric EDTA at 2% (IronFist) and 5% (Ferroxx)
- Water control, i.e., no molluscicidal treatment (negative control)

Ten adult nematodes from one species were placed on each of five replicate plates per treatment, sealed with parafilm, and incubated at 18°C. After 4 days, the nematodes were gently poked with a platinum wire to check for movement/life.

Statistical analysis

Differences in percentage nematode mortality between the different bait treatments and controls were investigated using the Kruskal-Wallis test. Posthoc analysis was completed using Dunn's test incorporating the Bonferroni correction for multiple comparisons. All statistical analyses were carried out using IBM SPSS version 24.

Results and Discussion

For *P. papillosa* and *P. californica,* there were no differences in percent nematode mortality between the different molluscicide treatments and the control (Figures 1 and 2). These results suggest that widely used active ingredients are not lethal to these nematode species.

However, for *P. hermaphrodita* (Figure 3), which has been commercialized in Europe as Nemaslug, GardenSafe caused greater ($P < 0.001$) mean ($\pm$SE) percent nematode mortality (58.00 ± 5.83) than IronWorxx (2.00 ± 2.00) or IronFist (2.00 ± 2.00). This is a surprising result because, according to the GardenSafe label, the only active ingredient present in the product is iron phosphate at 1% concentration. Iron phosphate is a chemical compound that is Generally Recognized As Safe (GRAS) by the U.S. Food and Drug Administration (FDA). Also, given that IronWorxx

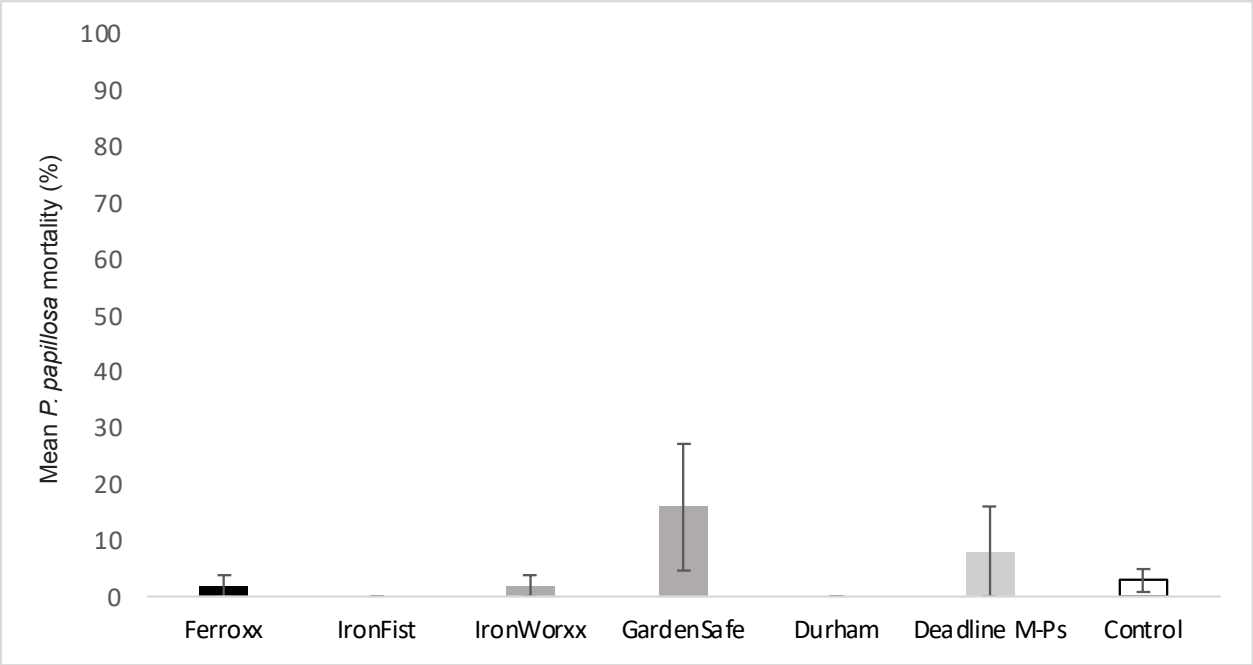

Figure 1. Mean (± SE) percentage *Phasmarhabditis papillosa* mortality when exposed to sodium ferric EDTA (Ferroxx and IronFist), iron phosphate (IronWorxx and GardenSafe), and metaldehyde (Durham Granules 7.5 and Deadline M-Ps) based slug baits. Controls were water only. There were no statistical differences between treatments ($KW = 7.376$, $P = 0.287$).

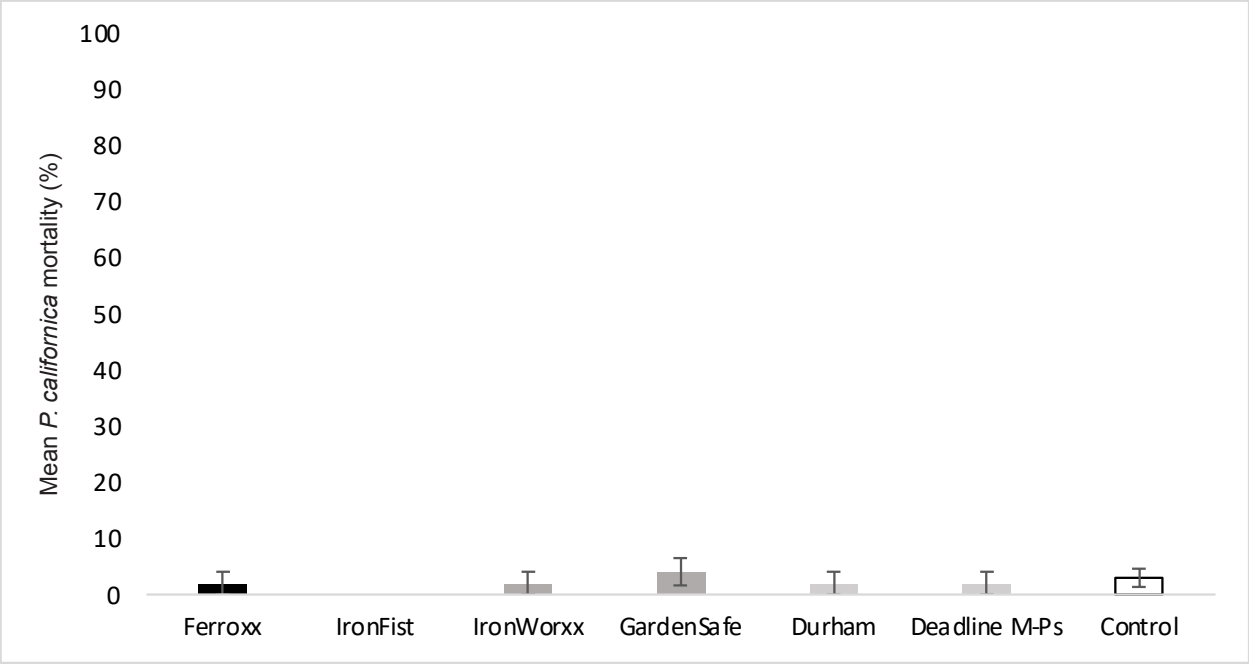

Figure 2. Mean (± SE) percentage *Phasmarhabditis californica* mortality when exposed to sodium ferric EDTA (Ferroxx and IronFist), iron phosphate (IronWorxx and GardenSafe), and metaldehyde (Durham Granules 7.5 and Deadline M-Ps) based slug baits. Controls were water only. There were no statistical differences between treatments ($KW = 2.656$, $P = 0.851$).

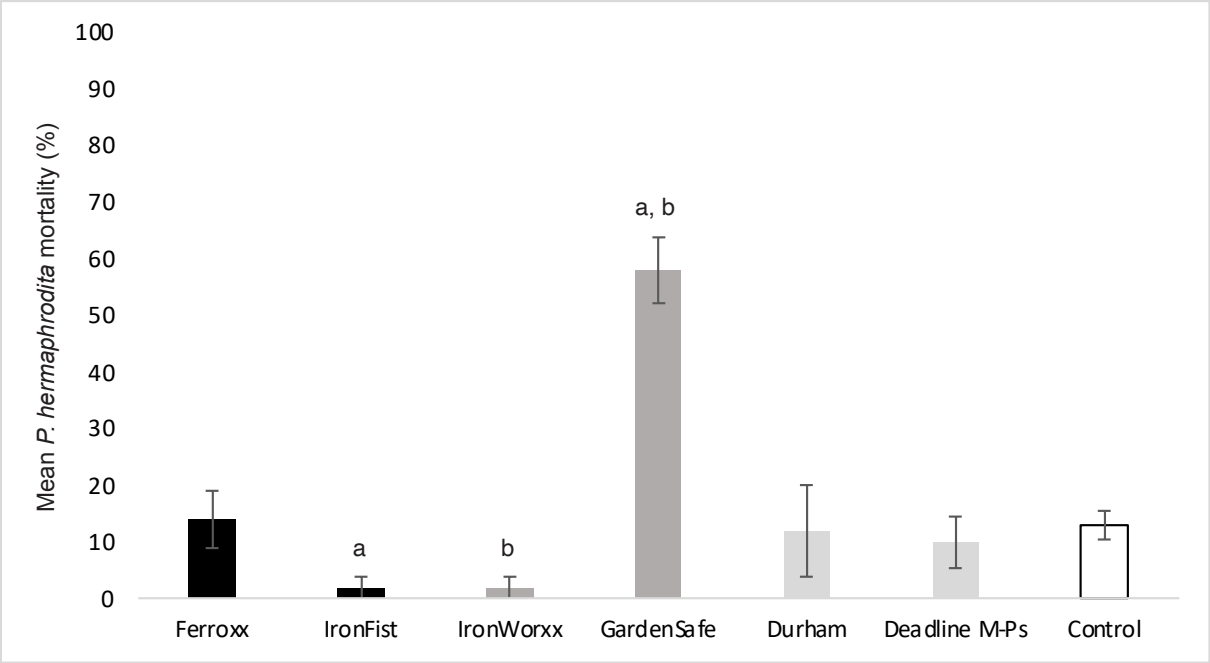

Figure 3. Mean (± SE) percentage *Phasmarhabditis hermaphrodita* mortality when exposed to sodium ferric EDTA (Ferroxx and IronFist), iron phosphate (IronWorxx and GardenSafe), and metaldehyde (Durham Granules 7.5 and Deadline M-Ps) based slug baits. Controls were water only. Statistical difference observed between certain treatments ($KW = 20.662$, $P = 0.002$). Bars with the same lowercase letter indicate significant differences in mortality between the treatment medians. a: test statistic = 27.30, $P < 0.001$. b: test statistic = 27.30, $P < 0.001$.

has an iron phosphate concentration of 3% and caused minimal nematode mortality (2.00 ± 2.00), it is unlikely that iron phosphate is lethal to *P. hermaphrodita*. It is likely that one of the other ingredients in GardenSafe is lethal to this nematode species but, because bait composition is largely proprietary information, it is difficult to determine what that ingredient could be.

GardenSafe is largely used by home gardeners, and such growers should be mindful of the potential lethal effects of this product to *P. hermaphrodita*. However, the slug baits (e.g., Deadline M-Ps and Ferroxx) that are most widely used by growers in the Willamette Valley had minimal impact on the survival of the three candidate nematode species. This suggests that if these nematodes are commercialized for slug control, it will be possible to use slug baits as part of an Integrated Pest Management approach in grass and clover seed production.

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Acknowledgments

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