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‘New species association’ biological control? Two coccinellid species and an invasive psyllid pest in New Zealand

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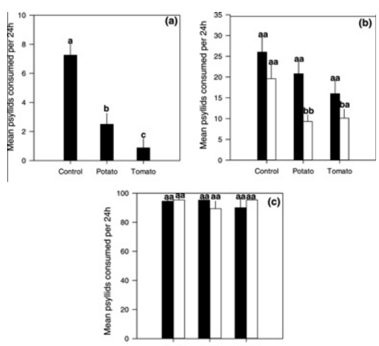
HIGHLIGHTS

- ▶ Two naturalized Australian coccinellid species consumed the invasive tomato–potato psyllid pest.
- ▶ Coccinellid size and life stage affected the number of psyllids consumed.
- ▶ Feeding substrate influenced psyllid consumption.

GRAPHICAL ABSTRACT



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ABSTRACT

The ‘new species association’ biological control approach is based on the ecological principle in which a natural enemy is used that has not coevolved with a pest. The recent incursion of the tomato–potato psyllid (TPP), *Bactericera cockerelli* to New Zealand offered a unique opportunity to investigate the potential of a new species association for biological control of this pest. This laboratory-based study investigated the potential for a new species association between two New Zealand naturalized coccinellids, *Cryptolaemus montrouzieri* and *Cleobora mellyi*, and TPP. A third naturalized New Zealand coccinellid, *Scymnus loewii*, was compared as a potential ‘old association’. We conducted two experiments to determine consumption rate and feeding behavior, respectively, of adults and fourth-instar larvae of the three coccinellid species on mixed instars of TPP nymphs, using tomato and potato leaflets, and a no-leaflet control. *C. montrouzieri* consumed up to 30 psyllids over 24 h, depending on leaflet type and predator life stage. *C. mellyi* adults and larvae were the most voracious predators of psyllids, consuming up to 100 TPP over 24 h. Adult *C. mellyi* spent more time feeding on psyllids in the control (56%) and potato leaflets (30%) than on tomato leaflets. Larvae spent 79% more time feeding on the no-leaflet control, compared to the potato (24%) and tomato leaflet (14%) treatments. *S. loewii* consumed relatively few psyllids on all three substrates (<10 over 24 h), and spent less time feeding compared to the other two species. By demonstrating that these predators will consume this psyllid, our results suggest that a new species association may potentially exist between *C. montrouzieri, C. mellyi* and the TPP.

1. Introduction

Classical biological control programmes generally involve some type of evolutionary relationship, whereby the natural enemy is sourced from the native area of the pest (e.g. Legner and Bellows, 1999; Hajek, 2004). This ‘old species association’ approach, where predator and prey species have co-evolved, may in practice reduce the likelihood of the predator/parasitoid species being effective biological control agents (Pimentel, 1963; Hajek, 2004). The ‘old species association’ reasoning assumes that interactions between a natural enemy and a pest originating in similar geographical

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regions will have moved towards a more stable association (Hajek, 2004). A 'new species association' approach is based on the ecological principle that a natural enemy that has not coevolved with a pest could be more effective (Pimentel et al., 1975; Hokkanen and Pimentel, 1984, 1989; Hajek, 2004; Irvin and Hoddle, 2010). Meta analysis demonstrated that new species associations are relatively successful in reducing the populations of the target pest species (Hokkanen and Pimentel, 1984, 1989). The assessment of 286 cases of successful biological control documented by Laing and Hamai (1976) utilizing both old and new associations, indicated a 75% greater success rate if the predator/parasitoid and its prey/host are newly associated (Hokkanen and Pimentel, 1984).

Further support for the new association approach has come from analyses of theoretical evidence and from those who have employed the technique in practice (e.g. Miller et al., 1987; Lawton, 1988; Dennill and Moran, 1989). For instance, Service (1981), when discussing ecological considerations in biological control strategies against mosquitoes, suggested that it is more appropriate to introduce exotic but newly associated pathogens and parasitoids that laboratory experiments have indicated have potential to kill mosquito larvae, than using those that currently coexist with the mosquitoes. However, others have rejected the new association approach (e.g. Cock, 1986; Waage and Greathead, 1988), arguing that species most likely to-be-effective new association biological control agents are pre-adapted to using new hosts and therefore pose relatively high risks to non-target species (Roderick, 1992). The recent incursion of TPP into New Zealand offers a unique opportunity to investigate the potential of a new species association for biological control of this pest.

The tomato–potato psyllid (TPP), *Bactericera cockerelli* Sulc. (Hemiptera: Triozidae), is a phytophagus phloem-feeding insect pest that has detrimental economic impacts to cultivated solanaeous crops in North and Central America, and more recently New Zealand (Yang and Liu, 2009). TPP has been reported to have an extensive host range of 20 plant families (Yang and Liu, 2009). However, some authors disagree, suggesting the real host plant range may be as low as three families, predominantly Solanaceae, Convolvulaceae and Menthaceae (Martin, 2008). Recently, the occurrence of TPP has been linked with substantial crop losses in tomato, potato and *Capsicum* spp. in North and Central America and New Zealand (Liu et al., 2006; Gill, 2006; Munyaneza et al., 2007). TPP is known to vector a new plant pathogen '*Candidatus* Liberibacter solanacearum' or '*Candidatus* Liberibacter psyllaurous', the cause of zebra chip disease, which has been associated with decreased growth and yield in potatoes, tomatoes and *Capsicum* spp. in North America and New Zealand (Munyaneza et al., 2007; Hansen et al., 2008; Liefting et al., 2008, 2009; Secor et al., 2009). TPP can also induce the physiological condition known as psyllid yellows (Sengoda et al., 2010) which has similar symptoms to zebra chip disease. However, once TPP are removed the plant can fully recover after 4 weeks (Sengoda et al., 2010).

Chemical suppression of TPP populations requires frequent applications of insecticides (Goolsby et al., 2007) with highly variable results (Gharalari et al., 2009; Berry et al., 2009). Furthermore, there is the potential that TPP may become pesticide resistant as the pesticides used, such as imidacloprid, abamectin and spirotetramat are not effective against adult TPP (Goolsby et al., 2007; Gharalari et al., 2009). With the exception of pathogenic fungi (Sánchez-Peña et al., 2007; Lacey et al., 2009, 2011), little is known about potential biological control agents available for TPP. There are a limited number of investigations on predatory suppression of TPP (e.g. Al-Jabr, 1999; Liu and Trumble, 2007), and considerable effort is going into developing a biological control for TPP in New Zealand in glasshouse crops (Workman and Whiteman, 2009; Workman and Walker, 2009).

Coccinellids (Coleoptera) are one of the most important insect groups used in biological control of agricultural pests (DeBach and Rosen, 1991), feeding on a wide variety of pest species (see DeBach and Hagen, 1964; DeBach and Rosen, 1991; Obrycki et al., 2009). Moreover, many coccinellid species prey on a variety of psyllid species (Pluke et al., 2005; see review by Hodek and Honěk, 2009). *Cleobora mellyi* Mulsant, the southern ladybird, is endemic and widespread throughout southern and central Australia (Ślipiński, 2007), feeding on larval chrysomelids, aphids and numerous psyllid species that occur in that country (Baker et al., 2003; Murray et al., 2008). *C. mellyi* was imported to New Zealand during the 1970s as a biological control agent of larvae of a chrysomelid, the eucalypt tortoise beetle (*Paropsis charybdis* Stal), a major pest of *Eucalyptus* spp. in forestry plantations (Baker et al., 2003). It is thought that this species may be a potential biological control for TPP, as *C. mellyi* is now well established in New Zealand (Berndt et al., 2010).

Another potential coccinellid biological control for TPP is *Cryptolaemus montrouzieri* Mulsant which is indigenous to the Australasian Zoogeographic Region (Booth and Pope, 1986) and was among the first species to be used as a biological control agent of agricultural pests (Hodek, 1973; Booth and Pope, 1986). *C. montrouzieri* has been imported into over 40 countries, including New Zealand, to combat mealybug pests (Clausen 1978 cited in Booth and Pope, 1986). *Scymnus loewii* Mulsant naturally occurs throughout much of the south-west United States (Gordon, 1985), and is a generalist predator, including prey such as aphids, mites and adelgids (Jones et al., 2002). *S. loewii* was an accidental immigrant to New Zealand, first recorded in Auckland in 1941 (Charles, 1989). In the United States the geographical range of *S. loewii* overlaps with that of the TPP, implying an evolutionary history between these two organisms. Therefore, the possibility of an 'old association' between *S. loewii* and TPP cannot be discounted. Conversely, *C. mellyi* and *C. montrouzieri* have no evolutionary history with TPP, as this psyllid species does not occur in Australia. Therefore, *C. mellyi* and *C. montrouzieri* provide an opportunity to investigate a potential 'new species association'.

Consumption of TPP by these two Australian coccinellids was compared with that of *S. loewii*, as there is no record whether *Scymnus* spp. consume or associate with *B. cockerelli*. This laboratory study examined the mean maximum consumption of TPP nymphs by adults and fourth-instar larvae of the three coccinellid species (except *S. loewii* larvae) over 24 h. We also investigated the effect that the feeding substrate had on coccinellid feeding behavior on TPP. The results of this study can inform future work on TPP in New Zealand, in which 'new species associations' could be further examined in the field.

2. Materials and methods

2.1. Experimental insects

Field-collected TPP, obtained from Epicurean Supplies Ltd. (Havelock North, New Zealand), were reared on a mixture of potato (*Solanum tuberosum* cv. Ilam Hardy), bell pepper (*Capsicum annuum* cv. Giant Bell) and tomato (*Solanum lycopersicum* cv. Grosse Lisse). Psyllid cultures were maintained in Perspex cages ($70 \times 70 \times 70$ cm) with mesh doors in controlled temperature rooms at 23 °C (±2 °C) and a 16/8 h day/night cycle. Light intensity was ca. 120 μmols m^{-2} s^{-1}.

Adult and larval stages of *S. loewii*, *C. montrouzieri*, and *C. mellyi* were supplied by Zonda Resources (Auckland, New Zealand). Adult fresh-weights of these three species after a 24 h starvation period were 2.0 ± 0.2, 7.80 ± 1.37 and 50.8 ± 3.3 mg, respectively. Cultures were established and maintained under controlled conditions (see above) until required. Coccinellids were maintained on a variety of