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Diet-dependent cannibalism in the omnivorous phytoseiid mite *Amblydromalus limonicus*

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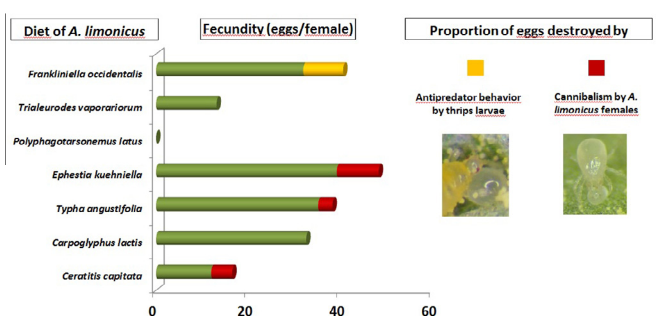
HIGHLIGHTS

- *A. limonicus* showed good population growth on *F. occidentalis*.
- The performance of *A. limonicus* fed on *T. vaporariorum* and *P. latus* was poor.
- *T. angustifolia*, *E. kuehniella* and *C. lactis* were excellent foods for *A. limonicus*.
- Antipredator behavior of thrips reduced population growth of *A. limonicus*.
- Cannibalism in *A. limonicus* was diet-dependent.

GRAPHICAL ABSTRACT



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ABSTRACT

Amblydromalus limonicus (Garman & McGregor) (Acari: Phytoseiidae) is a commercially available predator of key pests in protected crops, particularly of thrips and whiteflies. Basic information on the developmental and reproductive performance of the predator as a function of food is largely lacking. In the present study, development, reproduction and growth rates were determined for *A. limonicus* on four economically important pests: Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), broad mite, *Polyphagotarsonemus latus* (Banks) (Acari: Tarsonemidae) and two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). The life history traits of females fed on these different target prey were compared with those of females offered *Carpoglyphus lactis* L. (Acari: Carpoglyphidae), which is the standard food source for mass-producing this predator. Additionally, three commercially available non-prey food sources with potential for use in the mass production or as supplementary food to sustain populations of the predator in the field were tested: the commercial pollen product Nutrimite (consisting of pollen of narrow-leaved cattail, *Typha angustifolia* L.), frozen eggs of the Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) and frozen eggs of the Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae). Survival rates of immature *A. limonicus* were high (>94% survival) on all tested foods except on *T. vaporariorum* and *T. urticae* (76.0% and 17.1%, respectively). The fastest development was obtained when mites were fed on *T. angustifolia*, whereas the longest developmental times were obtained on *T. urticae* and *T. vaporariorum*. When females were offered *P. latus*, no reproduction was observed, despite a high prey consumption in both the juvenile and adult stages. The reproductive performance of *A. limonicus* fed on *T. vaporariorum* was significantly lower than that on

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F. occidentalis. Furthermore, no second generation could be obtained on a diet solely consisting of *T. vaporariorum*. Population growth rates were highest when *A. limonicus* was fed on Nutrimite, *E. kuehniella* or *C. lactis*, and exceeded those on a diet consisting of their natural prey, *F. occidentalis*. The phytoseiid showed cannibalistic behavior when maintained on *E. kuehniella* and *C. capitata* eggs and *T. angustifolia* pollen, with females consuming their own eggs. The rate of cannibalism was dependent on the food source offered, but always resulted in reduced population growth rates. This cannibalistic behavior should be taken into account when selecting food sources for mass rearing of *A. limonicus* or supporting its populations in the field.

1. Introduction

Western flower thrips (WFT), *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) and greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), are major destructive pests in agricultural crops worldwide (Osborne and Landa, 1992; Lewis, 1997; Kirk and Terry, 2003). Chemical control of these virus-vectoring herbivores is impeded by their fast development of insecticide resistance (Jensen, 2000; Gorman et al., 2002; Jones et al., 2003; Bielza, 2008), leading to high control costs due to increasing pesticide use (van Lenteren, 2000). Therefore, other pest control strategies, including the introduction of biological control agents in the crop, may contribute towards a more sustainable pest management. Among these natural enemies, phytoseiid predatory mites have been shown to contribute to the suppression of both thrips and whitefly pests (Ramakers, 1980; Nomikou et al., 2002; Messelink et al., 2006; Wimmer et al., 2008). Currently, *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae) is the dominant phytoseiid predator used in protected cultivation for thrips control (van Lenteren, 2012), and has also shown to successfully suppress whitefly populations (Nomikou et al., 2001; Messelink et al., 2008). However, this phytoseiid originates from Mediterranean climates (Ragusa and Swirski, 1977), resulting in lower performances below 18 °C (Hoogerbrugge et al., 2011). Likewise, other generalist phytoseiids that are commercially available, such as *Neoseiulus cucumeris* (Oudemans) and *Transeius montdorensis* (Schicha) also prefer higher temperatures (Morewood and Gilkeson, 1991; van Houten et al., 1995; Knapp et al., 2013). Preventive releases of predatory mites in temperate greenhouses are often done early in the season, with lower initial temperatures for the build-up of predator populations. Therefore, other predatory mites that start reproducing at lower temperatures, such as *Amblydromalus limonicus* (Garman & McGregor), might constitute a suitable alternative for augmentative releases at lower temperatures (van Houten et al., 1995; Hoogerbrugge et al., 2011).

A. limonicus has been classified as a type III generalist predator (McMurtry and Croft, 1997). It feeds on various types of prey including thrips, whiteflies, and tetranychid, eriophyoid, and tydeid mites (Chant and Fleschner, 1960; McMurtry and Scriven, 1965; Swirski and Dorzia, 1968; Kennett and Hamai, 1980; Hoogerbrugge et al., 2011). Its non-prey food spectrum consists of different kinds of pollen, extra-floral nectar, honeydew, fungi and even leaf tissue (McMurtry and Scriven, 1965; Swirski and Dorzia, 1968; Messelink et al., 2006; Vangansbeke et al., 2014). Greenhouse experiments have demonstrated the potential of *A. limonicus* to control thrips and whitefly infestations in strawberries and cucumbers (Messelink et al., 2006; Hoogerbrugge et al., 2011; Knapp et al., 2013). Due to difficulties in the mass rearing, the predator was not commercialized for application in protected cultivation until a viable mass-production system became recently available (Messelink et al., 2006; Knapp et al., 2013).

Besides some brief reports on the biology and control potential of *A. limonicus*, profound studies focusing on its developmental and reproductive performance as a function of food are largely lacking. In this study, we conducted laboratory experiments to calculate life tables for *A. limonicus* on four pests of high economic importance: *F. occidentalis*, *T. vaporariorum*, the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae) and the broad mite *Polyphagotarsonemus latus* (Banks) (Acari: Tarsonemidae). The performance of *A. limonicus* on these target prey was compared with a that on the dried fruit mite, *Carpoglyphus lactis* L. (Acari: Carpoglyphidae), which is the main food source used for mass rearing the predator. Additionally, three commercially available non-prey food sources with potential for use in the mass production or as a supplementary food to sustain populations of the predator in the field were tested: the pollen product Nutrimite (consisting of pollen of narrow-leaved cattail, *Typha angustifolia* L.), frozen eggs of the Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) and frozen eggs of the Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), which were recently found to be an excellent food source for *A. limonicus* (Vangansbeke et al., 2014).

2. Materials and methods

2.1. Cultures and foods

A stock culture of *A. limonicus* was initiated with mites obtained from Koppert B.V. (Berkel en Rodenrijs, The Netherlands). The mites were reared on reversed kidney bean leaves (*Phaseolus vulgaris* L.) placed on water-soaked cotton in a petri dish (ø 13.3 cm). The edges of the bean leaf were covered with an additional layer of cotton to provide free water and to serve as an escape barrier. Biweekly, cattail pollen (*Typha latifolia* L.) was dusted over the leaves as a food source. Two-spotted spider mites were collected from castor bean (*Ricinus communis* L.) at the Faculty of Bioscience Engineering of Ghent University (Ghent, Belgium) and a laboratory colony was maintained on kidney bean plants. Greenhouse whiteflies, *T. vaporariorum*, were provided by Koppert B.V. and were reared on potted *Solanum lycopersicon* L. cv "Moneymaker" plants. Broad mites, *P. latus*, were collected from potted azalea plants (*Rhododendron simsii* cv. "Nordlicht") at the Ornamental Plant Research station (Destelbergen, Belgium). Infested flower buds were subsequently transferred to reversed bean leaf arenas as described above. Western flower thrips were collected from rose plants (*Rosa hybrida* L. cv. 'Red Naomi') at the Ornamental Plant Research station and were cultured in plastic boxes on green bean pods (*P. vulgaris*) placed on a layer of vermiculite.

All colonies were kept in climatic cabinets at 25 ± 1 °C, 70 ± 5% RH and a 16:8 h (L:D) photoperiod.

Dried fruit mites, *C. lactis* L., were provided by Koppert B.V. and were stored in their wheat bran substrate at 18 °C. A commercial pollen product (Nutrimite), purchased from Biobest N.V. (Westerlo, Belgium), was identified to consist of pollen of narrow-leaved cattail, *T. angustifolia*. The identity of the product was confirmed by Biobest N.V. (Juliette Pijnakker, personal communication).