



Review

Scale insects, mealybugs, whiteflies and psyllids (Hemiptera, Sternorrhyncha) as prey of ladybirds

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ABSTRACT

This review surveys the literature dealing with food relationships of coccidophagous, aleurodophagous and psyllophagous coccinellids. While in the cold temperate climate aphids are the dominant prey group (68% of ladybird species), globally, coccids are the dominant prey group of 36% of coccinellid species, and only 20% prey primarily on aphids. Special attention is given to the physiological and environmental factors that affect the nutritive suitability of prey. In particular, the physiological states and development stages of the predators and prey species, sensory cues used in foraging, interspecific differences in the suitability of prey, the effects of host plants on predator–prey interactions, and climatic and seasonal effects on predation are discussed. Considerably more research has been conducted on the utility of coccinellids as predators of coccids than on aleyrodids and psyllids, in part because of the characteristics of whiteflies that restrict their consumption by polyphagous species. A major conclusion is that the assumption that coccinellids (and other predators) are of limited value in managing these non-aphid sternorrhynchans is premature, and that more research is sorely needed on these prey groups from predator ecologists.

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1. Introduction

Coccinellidae feed on a wide variety of prey species (Hodek, 1996), e.g. mites (Biddinger et al., 2009), aphids (Obrycki et al., 2009), Coleoptera and Lepidoptera (Evans, 2009), and non-prey food (Lundgren, 2009; Sutherland and Parrella, 2009). This review focuses on three kinds of prey: coccids (scales and mealybugs), aleyrodids (whiteflies), and psyllids, i.e. Hemiptera Sternorrhyncha other than aphids. Coccids are essential food for a large proportion (36%) of coccinellid species globally, especially in the tropics and subtropics.

Although prey specialization occurs even within individual tribes of coccinellids, such as Coccinellini, there is a tendency for coccinellids to feed on common prey groups at the tribal level. Coccidophagy is likely the ancestral condition for the family Coccinellidae (Giorgi et al., 2009), and coccidophagous coccinellids belong to several tribes (and genera), including Sukunahikonini, Sticholotini, Scymnini (*Cryptolaemus*, *Diomus*, *Nephus*, *Sidis*), Hyperaspini (*Hyperaspis*), Telsimiini, Chilacorini (*Chilocorus*, *Exochomus*), Coc-

cidulini (*Rhyzobius*), Azyini, Exoplectrini, Noviini (*Novius*, *Rodolia*), and Coccinellini (*Neda*). Psyllids are consumed preferentially by coccinellids in the tribe Ortaliini, and occasionally Coccinellini. Species from Serangiini, Scymnini (*Clitostethus*), and Scymnillini prefer aleyrodids as prey. (For a table of all groups of preys of ladybirds see Hodek, 1996, pp. 144–145.)

An exact evidence of trophic ecology of coccinellids can only be gained by a systematic, preferably experimental study. The finding that some food may be eaten by ladybirds in spite of its low suitability or even toxicity (Hodek, 1956; Blackman, 1965) led to the principal distinction between essential food promoting successful preimaginal development and reproduction, while alternative foods only enable survival (Hodek, 1962, 1996). Here, we discuss some of the trophic ecology of lady beetles that specialize on non-aphid, hemipteran insects.

2. Scale insects (Coccoidea)

2.1. Economic importance of coccids and coccidophagous ladybirds

While globally, coccids are the dominant prey group for 36% of coccinellid species, and while only 20% consume primarily

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aphids, 68% of temperate ladybird species consume aphids (Klausnitzer and Klausnitzer, 1997). Majerus (1994) gives a very useful list of principal and secondary foods of British coccinellids (without defining these two categories), where coccids are listed as secondary prey for 16 primarily aphidophagous species, including, among others, *Adalia bipunctata* (L.) and *Coccinella septempunctata* L. The helpful food list of Klausnitzer and Klausnitzer (1997) for central-European Coccinellidae gives examples of prey consumed by ladybirds in the field under authors' observations (for a world perspective, see Giorgi et al., 2009).

Coccids damage many crops of economic importance, particularly woody species. However, eco- and ethological studies on coccidophagous ladybirds are scarce. In our view, this is due in part to their much greater success in "classical" biological control. Attempts at much more difficult augmentative and conservation biological control of aphids have apparently incited more intensive ecological and behavioral research of this guild of lady beetles (Obrycki et al., 2009). Two case studies, involving *Rodolia cardinalis* (Mulsant) and *Cryptolaemus montrouzieri* Mulsant, demonstrate that coccidophagous ladybirds can be excellent biological control agents.

2.1.1. *Rodolia cardinalis*

A textbook case of classical biological control occurred in the USA, when *R. cardinalis* was introduced in 1888 to California to reduce populations of the invasive *Icerya purchasi* Maskell in citrus groves (DeBach and Schlinger, 1964; Caltagirone and Douth, 1989). The scarce occurrence of *I. purchasi* in its native Australia was correctly believed to be caused by the top-down regulation of this species by natural enemies. This led to the historical introduction of *R. cardinalis* and the parasitoid *Cryptochaetum* sp. to California, and the subsequent successful reduction of *I. purchasi* populations there and elsewhere around the world (DeBach and Schlinger, 1964). However, it was not until 100 years later that the role of natural enemies of *R. cardinalis* in Australia was definitively established when they were experimentally excluded from *Acacia* trees (Prasad, 1989).

The basic reason for the success of this biological control program was explained by Thorpe (1930, p. 937) and Hodek (1973, p. 215): the "rate of increase ratio between the (introduced) predator and prey was in favour of the coccinellid" and stressed also later (Hagen, 1974; Hodek and Honěk, 1996; Kindlmann and Dixon, 1999; Dixon, 2000; Hodek and Michaud, 2008). Many other coccidophagous ladybirds have similar favorable rates of increase relative to those of their coccid prey, and have thus been successfully established as efficient classical biological control agents, particularly in warm temperate or subtropical regions such as Hawaii, West Africa, Kenya, and Fiji (DeBach and Schlinger, 1964).

2.1.2. *Cryptolaemus montrouzieri*

The mealybug destroyer *Cryptolaemus montrouzieri* failed to become established after its introduction into the USA in 1892, except along the southern California coast, probably because it cannot survive winters and has a limited ability to spread (DeBach and Hagen, 1964). It has to be mass-cultured on mealybugs reared on potato sprouts and periodically released inoculatively in citrus groves. *Cryptolaemus montrouzieri* has successfully controlled *Pseudococcus citri* (Risso) in citrus groves, and both *Pseudococcus citri* and *Phenacoccus gossypii* Townsend & Cockerell in California glasshouses on gardenias and chrysanthemums, respectively (DeBach and Schlinger, 1964). On citrus on the northern Black Sea coast, *C. montrouzieri* controlled *Pseudococcus gahani* Green and *Pulvinaria aurantii* Cockerell (DeBach and Schlinger, 1964).

2.1.3. Other coccid biological control agents

The impact of coccinellid predators of scales is not limited to the above two well-known species. *Chilocorus stigma* (Say) and *Microweisea misella* (Le Conte) killed on average 70% of pine needle scales, *Chionaspis pinifoliae* (Fitch) and *Chionaspis heterophyllae* Cooley, in unsprayed Christmas tree plantations in lower Michigan (Fondren and McCullough, 2005). Early instars of the soft scales, *Toumeyella pini* (King) and *T. parvicornis* (Cockerell), on *Pinus* spp. in Colorado, were preyed upon by *Coccinella septempunctata* L. and *Hippodamia convergens* (Guerin-Meneville), coccinellid species that are generally regarded as aphidophagous (Cooper and Cranshaw, 2004). *Fiorinia externa* Ferris (Diaspididae), an introduced pest of the eastern hemlock, *Tsuga canadensis* (L.) Carriere, was preyed upon by five coccinellid species in eastern Tennessee and western North Carolina. Three species, *Chilocorus stigma* (Say), *Rhyzobius lophantae* Blaisdell and *Scymnillus horni* (Gordon), were dominant while two others were found in low numbers (*Harmonia axyridis* Pallas, *Scymnus lowei* Mulsant). Lynch et al. (2006) considered the natural abundance of predators sufficient to reduce *F. externa* significantly in the region. The efficacy of coccinellids *Nephus bilucernarius* Mulsant and *Sticholotis rufipes* Weise (present at 0.1–1.8 and 0.05–0.2 individuals per plant, respectively) on Oahu and Maui in pineapple fields infested with the mealybugs *Dysmicoccus brevipes* (Cockerell) and *D. neobrevipes* Beardsley, was lowered by the interference of the ant *Pheidole megacephala* (F.) (González-Hernández et al., 1999).

2.2. Food specificity of coccidophagous ladybirds

2.2.1. Non-coccid food

Many coccinellids consume non-prey foods as a critical part of their diet (Hodek, 1996, chapter 6.1.1.2; Lundgren, 2009). For example, gut dissections confirmed that adults of the introduced coccidophagous *Chilocorus kuwanae* Silvestri were observed feeding on the nectar and pollen of two *Euonymus* spp. in North Carolina, USA (Nalepa et al., 1992).

To improve the economy of mass production of coccidophagous lady beetles, scientists have employed factitious prey with notable success. In many cases, eggs of Lepidoptera are a good factitious prey for coccidophagous lady beetles, as with the larvae of mealybug predator, *Cryptolaemus montrouzieri*, which can be successfully reared on the eggs of *Sitotroga cerealella* (Olivier). Neither preimaginal survival, nor weight at eclosion were reduced on this factitious prey (Pilipjuk et al., 1982). Diets developed by Okada (1970) for *Chilocorus* spp. were based on honeybee brood. However, the most satisfactory honeybee-brood diets also contained royal jelly and other supplements (Hattingh and Samways, 1993).

Reports on cannibalism in coccidophagous ladybirds are almost nonexistent, in contrast to aphidophagous species. It does not seem surprising, as the population dynamics of coccids are much more stable than those of aphids. Cannibalism has generally been considered as an adaptation to the highly variable abundance of prey (Osawa, 1992; Hodek, 1996).

2.2.2. Plant mediated effects on prey quality

Almost all reported cases of unsuitable coccid prey concern herbivores that derive chemical protection from their host plants. An early observation on the rejection by *Rodolia cardinalis* of *Icerya purchasi*, that fed on *Spartium* (Fabaceae) or *Genista* (Fabaceae) was not explained satisfactorily. Shortage of shade to the eggs of the predator (Savastano, 1918), or smell of the plants (Balachovsky, 1930) were the suspected causes. However, the ladybirds also rejected the coccids, isolated from the host plants (Poutiers, 1930). Hodek (1996) supposed that substances sucked from plants (e.g. the alkaloid spartein) render *I. purchasi* unpalatable for *R. cardinalis*.

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