Development and oviposition of predacious insects, *Stethorus japonicus* (Coleoptera: Coccinellidae), *Oligota kashmirica benefica* (Coleoptera: Staphylinidae), and *Scolothrips takahashii* (Thysanoptera: Thripidae) reared on different spider mite species (Acari: Tetranychidae)[†]

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Abstract

The development and oviposition of three predacious insects, *Stethorus japonicus*, *Oligota kashmirica benefica*, and *Scolothrips takahashii*, reared on different species of spider mites were studied at 27°C: 16L8D. Eggs and deutonymphs of three species of spider mites, *Panonychus mori*, *Tetranychus urticae*, and *Amphitetranychus viennensis*, which are pest species on Japanese pear, were provided as the prey for the predacious insects. The quality of each spider mite species as prey differed markedly among the three predacious insect species. Both the development and oviposition of *S. japonicus* differed greatly with the prey species. *A. viennensis* was a superior prey for both development and oviposition, while *P. mori* was not. In particular, most larvae reared on *P. mori* eggs died during the first stadium and only about 10% of larvae developed to pupae. Most larvae of *O. kashmirica benefica* reared on *P. mori* eggs also died during the first stadium. However, their development and oviposition were not greatly affected by the difference in prey species. *S. takahashii* developed and oviposited well regardless of the prey species examined, except that larvae reared on *P. mori* deutonymphs required more time to complete development.

Key words: *Stethorus japonicus*; *Oligota kashmirica benefica*; *Scolothrips takahashii*; prey species; development and oviposition

INTRODUCTION

Prey specificity including prey range and preference is one of the most important aspects for consideration when evaluating the effects of natural enemies (e.g. McMurtry, 1982; Sabelis and Dicke, 1985). In particular, for crops on which multiple target prey species occur, the study of prey specificity is indispensable for evaluating the effect of the predator on the suppression of each target species (e.g. Dicke, 1988). On deciduous fruit trees such as Japanese pear, apple and peach, a wide variety of genera and species of spider mites cause serious damage (Ehara and Shinkaji, 1975) and then often occur simultaneously. Thus, for the effective use of natural enemies against these spider mites, prey specificity needs to be investigated.

The predacious insects, *Stethorus japonicus* H. Kamiya (Coleoptera: Coccinellidae), *Oligota kashmirica benefica* Naomi (Coleoptera: Staphylinidae) and *Scolothrips takahashii* Priesner (Thysanoptera: Thripidae) are native to Japan, and are considered to be prospective natural enemies for spider mites, as well as phytoseiid mites (Amano, 1996). The predation capacities of these predacious insects are superior to those of phytoseiid mites, whereas colonization in spider mite patches is inferior in the former when spider mite densities are low (Chazeau, 1985; Amano, 1996). Although these predacious insects are specialized to spider mites, they were considered to have wide prey ranges within spider mites (Chazeau, 1985; Amano, 1996). However, little is known about their prey specificity.

Kishimoto (2002) studied the seasonal occurrence of spider mites and their predators in Japanese pear orchards with the different dominant spider mite species, *Amphitetranychus viennensis* (Zacher), *Tetranychus urticae* Koch or *Panonychus citri* (McGregor), and showed that their response to

the density of each spider mite species differed with the predacious insect species: *S. japonicus* occurred even when the spider mite density was low in an orchard where either *A. viennensis* or *T. urticae* was dominant, whereas it began to occur when the spider mite densities became high in an orchard where *P. citri* was dominant. *S. takahashii* occurred even when the spider mite density was low in an orchard where *T. urticae* was dominant. On the other hand, *Oligota* spp. (mostly *O. kashmirica benefica*) began to occur when the spider mite density became high, irrespective of the mite species. One possible factor affecting the differences in the response of these predacious insects to the density of each spider mite species may be the difference in prey specificity. This study focussed on the difference in prey quality with the spider mite species, which is an important factor affecting prey specificity in the three predacious insects: the development and oviposition reared on different spider mite species were compared.

MATERIALS AND METHODS

Predacious insects and prey spider mites. The predacious insects used in this study, *S. japonicus*, *O. kashmirica benefica*, and *S. takahashii*, were collected from a Japanese pear orchard at the National Institute of Fruit Tree Science, Tsukuba, in September 1997. They were reared on lima bean leaf (*Phaseolus lunatus* L.) discs with sufficient prey, *T. urticae*, in a laboratory at 20°C: 16L8D. A bean leaf was placed on the top of a pad of cotton wool saturated with water in a petri dish (9 cm diameter and 1.4 cm depth). These leaf discs were placed in sealed containers (30 cm×20 cm×6 cm) to prevent the predators from flying away.

Three species of spider mites belonging to different genera, *A. viennensis*, *T. urticae* and *Panonychus mori* Yokoyama, were examined as prey of these predacious insects. As *P. citri* was the dominant *Panonychus* species in the pear orchards of my previous study (Kishimoto, 2002), this species was considered ideal for the present study. However, this species was inconvenient for experimental use because the population increase of *P. citri* on pear leaves is suppressed until mid-summer (Gotoh and Kubota, 1997). Therefore, I substituted a closely related species, *P. mori*, formerly called the diapausing strain of *P. citri* (Ehara and Gotoh,

1992), because this species can maintain its population over years on Japanese pear leaves. *T. urticae* and *A. viennensis* were collected from pear orchards at the National Institute of Fruit Tree Science, Tsukuba, in August and October 1997, respectively. *P. mori* was collected as overwintering eggs from a pear orchard in Daiei, Tottori Prefecture, in March 1998. *T. urticae* were reared on lima bean leaf discs and *A. viennensis* and *P. mori* were reared on pear leaf discs at 23°C: 16L8D.

Development and oviposition of the predacious insects reared on the different prey species. The prey stages of each spider mite species were the egg and deutonymph. A great difference that may affect predation exists at least in the egg morphology of the species: the egg of *P. mori* has a hard shell which is peculiar to *Panonychus* species (Beament, 1951), whereas the egg shells of *T. urticae* and *A. viennensis* are soft. On the other hand, little difference that may affect the predation seems to exist among species at least in the morphology of deutonymphs. An ample number of prey was provided per day in each experiment for each predator species (Table 1), based on a preliminary experiment and the studies of Nakagawa (1988) and Shimoda et al. (1993).

To determine developmental time in *S. japonicus* and *O. kashmirica benefica*, larvae of both sexes were used because the developmental time and the number of prey consumed were not significantly different between male and female larvae (T. Gotoh and T. Shimoda, personal communication). However, in *S. takahashii*, only female larvae were used because a difference in the number of prey consumed between male and female larvae was suggested (Nakagawa, 1988). Twenty to 30 adult females of each predator species were allowed to oviposit for 24 h on lima bean leaf discs with suffi-

Table 1. Number of prey provided per day in each experiment

Predator species	Stage	Prey stage	
		Egg	Deutonymph
S. japonicus	Larva, Adult	400	130
O. kashmirica benefica	Larva, Adult	220	70
S. takahashii	Larva	60	20
	Adult	110	35

cient *T. urticae* at 27°C: 16L8D, and then removed. Immediately after egg hatching, larvae of each species were transferred individually to pear leaf discs (5 cm×5 cm) with each stage of each spider mite species. The survival and developmental stage was checked every 8 h and the number of prey consumed was checked every 24 h throughout the larval development. The leaf discs were replaced with new ones immediately after the number of prey consumed was checked.

To determine the number of eggs deposited, adult females of each predator species from the stock cultures were used. These adult females were reared on each stage of each spider mite species 2 days before the commencement of the experiment to eliminate the effect of prey species. The stage of adult females was 3 to 5 days after the commence-

ment of oviposition, which was considered to be the peak oviposition rate. The adult females were transferred individually to pear leaf discs (5 cm× 5 cm) with each stage of each spider mite species. Each leaf disc was placed in a sealed container (8 cm diameter and 2 cm depth) to prevent individuals from flying away. The number of eggs deposited and prey consumption were checked every 24 h for 5 days at 27°C: 16L8D. The leaf discs were replaced with new ones immediately after the observation.

RESULTS

Development

Most of the *S. japonicus* larvae died during the first stadium and only 10% of them developed to
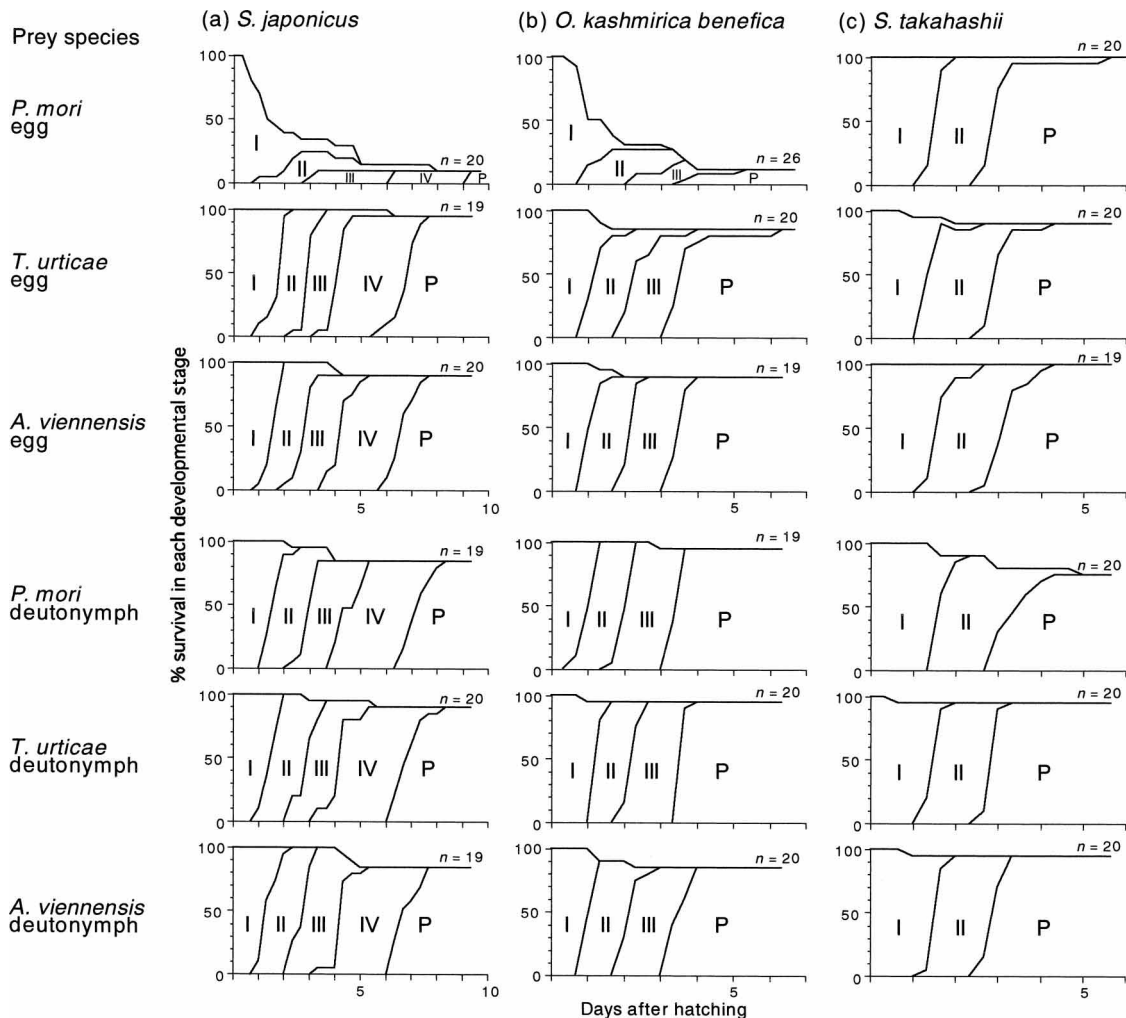

Fig. 1.   Survival rates and developmental characteristics of larvae of three predator species reared on different prey species (27°C: 16L8D). Roman numerals and P indicate the number of the larval stadiums and pupal stage, respectively.

Table 2. Prey consumption of three predator species on the first day after hatching

(a) *S. japonicus*

Prey species	n	% of larvae not feeding	No. of eggs consumed (mean±SE)
P. mori	20	45	6.95±1.89 a
T. urticae	20	0	17.40±1.36 b
A. viennensis	20	0	15.65±0.80 b

(b) *O. kashmirica benefica*

Prey species	n	% of larvae not feeding	No. of eggs consumed (mean±SE)
P. mori	26	53.8	5.04±1.43 a
T. uricae	20	0	23.75±2.91 b
A. viennensis	19	5.2	17.26±1.91 b

(c) *S. takahashii*

Prey species	n	% of larvae not feeding	No. of eggs consumed (mean±SE)
P. mori	20	0	12.05±0.65 b
T. uricae	19	0	8.37±0.77 a
A. viennensis	20	0	8.85±0.65 a

The same letter indicates that the means are not significantly different ($p>0.05$; Scheffé's method).

Table 3. Developmental time during the larval stage of three predator species reared on different prey species (27°C: 16L8D)

(a) *S. japonicus*

Prey species	The length of larval period (days)[a]	
	Egg	Deutonymph
P. mori	9.33±0 (2) b	7.33±0.13 (16) b
T. urticae	6.85±0.12 (18) a	6.94±0.13 (18) ab
A. viennensis	6.74±0.11 (18) a	6.85±0.13 (16) a

(b) *O. kashmirica benefica*

Prey species	The length of larval period (days)[a]	
	Egg	Deutonymph
P. mori	4.33±0.51 (3) a	3.54±0.04 (18) a
T. urticae	3.78±0.17 (17) a	3.68±0.02 (19) a
A. viennensis	3.61±0.05 (17) a	3.61±0.07 (17) a

(c) *S. takahashii*

Prey species	The length of larval period (days)[a]	
	Egg	Deutonymph
P. mori	3.15±0.14 (20) a	3.42±0.12 (15) b
T. urticae	3.09±0.07 (18) a	2.98±0.03 (19) a
A. viennensis	3.33±0.10 (19) a	3.05±0.05 (19) a

[a] Mean±SE.
Numerals in parentheses are the number of larvae tested. The same letter for the same prey stage indicates that the means are not significantly different ($p>0.05$; Scheffé's method).

pupae when they were reared on eggs of *P. mori*, whereas 90% or more larvae developed to pupae when they were reared on the eggs of the other prey species (Fig. 1a). About half of the first stadium larvae could not feed on any prey when they were reared on eggs of *P. mori* (Table 2a). Observations revealed that these larvae tried to bite the eggs with their mandibles repeatedly, but failed to break the eggshells, and finally gave up the attempt. Thus, they could consume fewer prey than those reared on eggs of the others on the first day after hatching (Table 2a). Eighty-five percent or more of the larvae completed development when they were reared on deutonymphs of each prey species tested (Fig. 1a). Larvae reared on *P. mori*, however, required a significantly longer time to complete development than those reared on *A. viennensis* (Table 3a). Larvae reared on *T. urticae* eggs consumed more prey than those reared on eggs of the other species during the larval development, and larvae reared on *A. viennensis* deutonymphs consumed fewer prey than those reared

on deutonymphs of the other species (Table 4a).

In *O. kashmirica benefica*, most of the larvae reared on *P. mori* eggs also died during the first stadium, as shown for *S. japonicus* (Fig. 1b). Prey consumption on the first day after hatching was also similar to that of *S. japonicus* (Table 2b). However, 85% or more of the larvae developed to pupae when they were reared on the other prey species and stages (Fig. 1b), and no significant difference was observed among prey species in regard to developmental time (Table 3b). There was also no significant difference in the total prey consumption among prey species in the deutonymphal stage, whereas larvae reared on *T. urticae* eggs consumed more prey (Table 4b).

Seventy-five percent or more of *S. takahashii*

Table 4.   Prey consumption during the larval stage of three predator species reared on different prey species (27°C: 16L8D)

(a) *S. japonicus*

Prey species	No. of prey consumed[a]	
	Egg	Deutonymph
P. mori	649.00± 0 (2) a	253.13±10.34 (16) b
T. urticae	833.78±22.57 (18) b	261.61± 9.52 (18) b
A. viennensis	657.06±16.25 (18) a	221.56± 4.96 (16) a

(b) *O. kashmirica benefica*

Prey species	No. of prey consumed[a]	
	Egg	Deutonymph
P. mori	280.67± 6.69 (3) a	93.33±4.10 (18) a
T. urticae	356.94±12.17 (17) b	83.21±2.91 (19) a
A. viennensis	287.77± 6.04 (17) a	82.41±4.60 (17) a

(c) *S. takahashii*

Prey species	No. of prey consumed[a]	
	Egg	Deutonymph
P. mori	48.45±2.65 (20) a	25.07±1.20 (15) b
T. urticae	52.44±3.04 (18) a	17.58±0.54 (19) a
A. viennensis	44.32±2.52 (19) a	20.63±1.15 (19) a

[a] Mean±SE.
Numerals in parentheses are the number of larvae tested. The same letter for the same prey stage indicates that the means are not significantly different (*p*>0.05; Scheffé's method).

Table 5.   Obviposition in adult females of three predator species reared on different prey species (27°C: 16L8D)

(a) *S. japonicus*

Prey species	No. of eggs per 5 days[a]	
	Egg	Deutonymph
P. mori	23.86±2.41 (14) a	30.14±2.74 (14) a
T. urticae	34.57±3.55 (14) ab	36.17±1.75 (12) ab
A. viennensis	40.64±4.74 (14) b	40.77±2.66 (13) b

(b) *O. kashmirica benefica*

Prey species	No. of eggs per 5 days[a]	
	Egg	Deutonymph
P. mori	27.27±2.25 (15) a	25.07±2.46 (14) a
T. urticae	29.62±3.81 (13) a	32.36±2.83 (14) a
A. viennensis	37.53±3.11 (15) a	33.21±3.01 (14) a

(c) *S. takahashii*

Prey species	No. of eggs per 5 days[a]	
	Egg	Deutonymph
P. mori	47.31±3.12 (13) a	37.54±3.41 (13) a
T. urticae	50.87±4.26 (15) a	39.67±2.97 (15) a
A. viennensis	54.40±3.81 (15) a	47.73±3.01 (15) a

[a] Mean±SE.
Numerals in parentheses are the number of females tested. The same letter for the same prey stage indicates that the means are not significantly different (*p*>0.05; Scheffé's method).

larvae could complete development regardless of prey species and stage (Fig. 1c). Unlike larvae of *S. japonicus* and *O. kashmirica benefica*, *S. takahashii* larvae could feed on *P. mori* eggs well (Table 2c). No significant differences were observed among prey species in regard to developmental time and total prey consumption, when they were reared on eggs (Tables 3c and 4c). But, larvae reared on *P. mori* deutonymphs required significantly more time and prey consumption to complete development (Tables 3c and 4c).

Oviposition

In *S. japonicus*, the number of eggs deposited differed significantly among prey species when they were reared with both egg and deutonymphal stages (Table 5a): females reared on *A. viennensis* laid more eggs than those reared on *P. mori*, and females on *T. urticae* showed an intermediate number of eggs. However, no significant difference was observed among prey species in regard to prey consumption when the prey stages provided were eggs or deutonymphs (Table 6a). In *O. kashmirica benefica*, no significant differences were observed among prey species in regard to the number of eggs deposited when the prey stages provided were eggs or deutonymphs (Table 5b). Prey consumption also did not differ significantly among prey species (Table 6b). In *S. takahashii*, no significant difference was observed among prey species in regard to the number of eggs deposited (Table 5c). There was also no significant difference in the prey consumption among prey species in the egg stage,

Table 6. Prey consumption in adult females of three predator species reared on different prey species (27°C: 16L8D)

(a) *S. japonicus*

Prey species	No. of prey consumed per 5 days[a]	
	Egg	Deutonymph
P. mori	1,234.43±44.06 (14) a	320.93±13.27 (14) a
T. urticae	1,284.21±50.96 (14) a	372.08±18.30 (12) a
A. viennensis	1,123.79±44.03 (14) a	331.31±14.25 (13) a

(b) *O. kashmirica benefica*

Prey species	No. of prey consumed per 5 days[a]	
	Egg	Deutonymph
P. mori	388.80±29.71 (15) a	180.86±10.80 (14) a
T. urticae	528.92±59.70 (13) a	177.93±10.92 (14) a
A. viennensis	452.13±27.59 (15) a	202.64±11.58 (14) a

(c) *S. takahashii*

Prey species	No. of prey consumed per 5 days[a]	
	Egg	Deutonymph
P. mori	346.54±11.86 (13) a	107.08±6.85 (13) a
T. urticae	304.53±22.88 (15) a	101.40±4.25 (15) a
A. viennensis	281.33±17.85 (15) a	131.07±6.09 (15) b

[a] Mean±SE.
Numerals in parentheses are the number of females tested. The same letter for the same prey stage indicates that the means are not significantly different ($p>0.05$; Scheffé's method).

whereas females reared on *A. viennensis* deutonymphs consumed more prey (Table 6c).

DISCUSSION

This study showed that the quality of each spider mite species as prey also differed with the three predacious insect species, as shown in phytoseiid mites (e.g. Ashihara et al., 1978; Mesa et al., 1990; Duso and Camporese, 1991). Both the development and oviposition rate of *S. japonicus* differed greatly with the prey species: *A. viennensis* was a superior prey but *P. mori* was inferior. The prey species had little affect on the development and oviposition rates of *O. kashmirica benefica*, except that most larvae reared on *P. mori* eggs died during the first stadium. *S. takahashii* developed and oviposited well regardless of the prey species examined except that larvae reared on *P. mori* deutonymphs required more time to complete development.

The high mortality of larvae of *S. japonicus* and *O. kashmirica benefica* may be because the hardness of *P. mori* eggshells prevented these larvae from feeding on them. On the other hand, the differences in the developmental time and oviposition rate among prey species observed in *S. japonicus* and in the developmental time in *S. takahashii* could not be explained in terms of the differences in the amount of prey consumption. Possible factors affecting the developmental time and oviposition may be of a physiological nature, such as nutrients.

The response of *S. japonicus* and *O. kashmirica benefica* to the density of each spider mite species observed in Japanese pear orchards (Kishimoto, 2002) might be related to the prey quality of each spider mite species shown in this study. *S. japonicus* seemed to respond to differences in prey species, for which prey quality differed with the spider mite species. It occurred even when the spider mite density was low in an orchard where a superior prey, *A. viennensis*, was dominant, whereas it began to occur when the spider mite density became high in an orchard where inferior prey, *P. citri* which was a closely related species of *P. mori*, was dominant. On the other hand, *O. kashmirica benefica* seemed to respond to prey densities rather than prey species, for the difference of prey quality of each spider mite species as food of this species was small. It began to occur when the spider mite density became high, and seldom occurred in the orchards where the spider mites density was low, irrespective of the dominant spider mite species.

The response of *S. takahashii* to the density of each spider mite species could not be explained in terms of prey quality. Although the prey quality of each spider mite species was virtually the same, this predator occurred even when the spider mite density was low in an orchard where *T. urticae* was dominant (Kishimoto, 2002). Such a discrepancy between the response to each prey species and the prey quality was also observed in *Typhlodromus occidentalis* (Hoy and Smilanick, 1981), *Amblyseius andersoni* and *A. finlandicus* (Sabelis and van de Baan, 1983). Besides prey quality, prey prefer-

ence can be affected by factors such as differences in the web or other residues produced by each spider mite species (Hoy and Smilanick, 1981) and the volatile kairomones emitted by each spider mite species feeding on leaves (Sabelis and van de Baan, 1983). Thus, further studies will be needed to understand the response of the predacious insects to each spider mite species.

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