Density suppression of the citrus red mite *Panonychus citri* (Acari: Tetranychidae) due to the occurrence of *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) on Satsuma mandarin

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Abstract

The seasonal prevalence of the citrus red mite and its predators on Satsuma mandarin trees was surveyed by naked-eye observation and the beating method in three commercial groves in Shizuoka Prefecture in 2003 and 2004. Of the predators, only phytoseiid mites were caught mainly by beating, and their population dynamics were synchronized with those of the citrus red mite from June to September. Most adult females of phytoseiid mites caught by beating belonged to the species *Neoseiulus californicus*. Furthermore, one population of *N. californicus* caught from a surveyed grove showed development and oviposition on the eggs of the citrus red mite as well as the *Tetranychus urticae* eggs under experimental conditions. These results indicate that an indigenous population of *N. californicus* in conventionally controlled citrus groves in central Japan has the ability to suppress the population of *P. citri* on Satsuma mandarin.

Key words: Citrus red mite; natural enemy; phytoseiid mite; *Neoseiulus californicus*; Satsuma mandarin

INTRODUCTION

In the 1960s and 1970s, many studies were conducted on the natural enemies of the citrus red mite *Panonychus citri* in citrus groves in Japan (Nakao et al., 1972; Tanaka and Inoue, 1973; Nakao, 1977). However, since groves sprayed with pesticides to control other insects and fungi had a poor population of natural enemies, it was concluded that chemical methods were necessary to control citrus red mites (Mori, 1964; Hamamura et al., 1984). Consequently, the populations of this species were observed to have developed acaricide resistance (Furuhashi, 1994; Masui et al., 1995), thereby rendering chemical control methods difficult in the 1980s and 1990s.

In contrast, introduction of the parasitic wasp of the arrowhead scale *Unaspis yanonensis* in 1980 led to a decrease in the use of organophosphorus insecticides in the 1990s (Furuhashi and Nishino,

1994). Since the late 1990s, there has been a shift in the use of insecticides used to control yellow tea thrips *Scirtothrips dorsalis* from the broad-spectrum type such as synthetic pyrethroids to the narrow-spectrum type such as chloronicotinyl. These changes in the use of insecticides sprayed in citrus groves might have increased the activity of natural enemies. Recent surveys in Shizuoka Prefecture revealed the occurrence of several natural enemies of the citrus red mite in commercial citrus groves (Masui and Ikeda, 2003; Tsuchiya, 2005).

Our surveys were conducted in commercial Satsuma mandarin groves in one of the main production areas in Shizuoka Prefecture and focused on the fauna and seasonal prevalence of natural enemies of the citrus red mite. These surveys show the prominent occurrence of a species of phytoseiid mites that has been considered a prospective phytoseiid mite for the suppression of spider mites (McMurtry and Croft, 1997) but is not yet reported in

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citrus groves in Japan. Experiments were conducted in an attempt to clarify the development and oviposition of this species while preying on the citrus red mite.

MATERIALS AND METHODS

Survey of citrus groves. This study was conducted in one commercial grove (A) in 2003 and two other groves (B and C) in 2004; these groves were located in Mikkabi in western Shizuoka Prefecture in central Japan. Although the size of each grove varied from 8 to 14 a, "Aoshima", the main variety of mandarin oranges in Shizuoka Prefecture, was cultivated in all the groves. From May to October, each grove was sprayed with organophosphorus insecticides (one or two times), chloronicotinyl (two or three times), and chlorphenapyr (two times) to control insect pests such as thrips, scales, and beetles, and with dithiocarbamate fungicides (three or four times) and others (two times) to control fungal pests such as melanose and gray mold. Spraying was conducted according to the conventional control calendar. The numbers of pesticide applications for the control of spider mites varied from one to two in each grove, i.e., all groves were sprayed with petroleum oil in mid-April, and groves A and C (but not grove B) were sprayed with acaricide in late September.

Population census. Five trees from each grove were observed from June 10 to October 2 in 2003 and from May 13 to October 22 in 2004. Naked-eye observation was conducted at intervals of one or two weeks; we counted the female adults of spider mites and predatory mites as well as adults and larvae of predatory insects present on 40 randomly selected spring leaves from the middle part of each census tree. At the same time, the beating method was applied to census trees; one branch in each of the four directions was beaten by hand, and the fallen material was collected using sticky film (20 cm×18 cm) set on a plastic board under a 1-cm-wide wire netting. The sticky film was covered with polythene film, transported to the laboratory in a cold box, and frozen until examined. All stages of predatory mites and insects on each sticky film were counted under a dissecting microscope. Further, the sticky film was cut such that the caught phytoseiid mites were collected along with a small margin of the film; these mites were then mounted

in gum-chloral medium on glass slides for identification.

Development and oviposition of an indigenous population of *Neoseiulus californicus* on the prey eggs of the citrus red mite. A population of *N. californicus* was collected from citrus trees in grove B in June 2004. Using *Tetranychus urticae* as the prey, *N. californicus* were reared on kidney bean leaflets laid on a wet cotton pad in Petri dish (9 cm in diameter) in a chamber maintained at $20\pm0.5^{\circ}\text{C}$ with a 16L:8D photoperiod. To maintain high humidity and prevent condensation, Petri dishes were placed in a plastic container (28 cm×21 cm×9.5 cm) with two holes (8 cm×7 cm) in the lid. In order to examine the developmental rate and period of preying on the eggs of *P. citri* or *T. urticae*, phytoseiid eggs that had been laid within 24 h were individually transferred to a citrus or kidney bean leaflet (2 cm×2 cm) on which 30 prey eggs had been placed after 10 prey females of each species had laid eggs at $25\pm1.0^{\circ}\text{C}$ for two days or one day, respectively. Phytoseiid development was observed, and the remaining prey eggs were counted daily until they reached adulthood under the rearing conditions. On the sixth day of the examination, the phytoseiid mites were transferred to a new leaflet with 30 prey eggs.

The phytoseiid females that had emerged within the previous 24 h were individually coupled with a male that had emerged within the previous three days; this coupling was conducted on a leaflet with 50 prey eggs for two days under the abovementioned conditions. On the third day, the females were transferred to a new leaflet; the leaflets were exchanged every two days for six days. The newly laid phytoseiid eggs and the prey eggs remaining on the leaflet were counted daily.

RESULTS

In the population surveys of spider mites and their natural enemies present on the leaves of Satsuma mandarin, few larvae of the *Oligota* sp. and lace-wings were observed in groves A and C, respectively; however, other predatory insects were not observed. Relatively large numbers of phytoseiid mites were observed in all the groves; the seasonal prevalence with regard to the density of adult females of spider mites and phytoseiid mites is illustrated in Fig. 1. From June to October, the popu-

lation density of the spider mite showed a peak in groves A and B, and two peaks were detected in grove C. The maximum densities in groves A and C were considerable higher than that in grove B. The time of the first detection of phytoseiid mites on leaves varied from early June to early August; this corresponded with the increase in the spider mite population in each grove. Their population densities increased rapidly and reached a peak either on the same day that the spider mite population peaked or 10–15 days later. The maximum

Fig. 1. Seasonal prevalence of population densities in adult females of *Panonychus citri* (●) and phytoseiid mites (○) on the leaves of Satsuma mandarin in commercial groves. Graph A indicates the prevalence in grove A in 2003, and graphs B and C show the prevalence in groves B and C in 2004.

densities of the phytoseiid mites also varied from 0.5 to 1.3 adult females per leaf; corresponding with the population densities of spider mites in each grove. Furthermore, these densities showed a rapid decrease coinciding with the decrease in the spider mite population.

Table 1 indicates the total number of predators caught by beating census trees in five surveys before and after each peak of the population density of the citrus red mite. Among the predatory insects, only one or two adults or larvae of the *Oligota* sp. and one lace-wing larva were caught in each grove. On the other hand, larger numbers of Phytoseiidae were caught during each peak in the population density of the spider mite in all groves, although a moderate number of Stigmaeidae was caught in grove A.

One hundred ninety-four adult females of phytoseiid mites collected from grove A and 35–58 individuals collected from other groves during each peak in the population density of the spider mite were identified as belonging to four species (Table 2). Only 1% or less of these belonged to *N. womersleyi*, *Typhlodromus vulgaris*, or *Euseius sojaensis*, and most of the phytoseiid mites from grove A were of the *N. californicus* species. Further, all the mites caught from groves B and C belonged to *N. californicus*.

Immature *N. californicus* that preyed on the eggs of both species of spider mites grew very well; their developmental rates were greater than 90%. Further, the developmental periods did not differ between the prey species (Table 3). No difference was observed in the number of prey eggs consumed by males, but a difference was observed with respect to females; during growth, the number of *P. citri* eggs consumed was greater than that of

Table 1. The composition of natural enemies of spider mite caught by beating the foliage of Satsuma mandarin trees

Field	Peak ^a	No. natural enemies of spider mite ^b			
		Phytoseiidae	Stigmaeidae	Staphylinidae	Chrysopidae
A	A1	763	62	1	1
B	B1	186	0	2	1
C	C1	1,093	7	1	0
	C2	301	1	2	1

^a Marks indicate each peak of the population density of the citrus red mite in Fig. 1.

^b Total number of natural enemies caught by beating in five surveys before and after each peak of the population density of citrus red mites.

Table 2. The species composition of adult females of phytoseiid mites caught by beating the foliage of Satsuma mandarin trees

Field	Peak ^a	No. female adults mounted	Species composition (%)			
			<i>N. californicus</i>	<i>N. womersleyi</i>	<i>E. sojaensis</i>	<i>T. vulgaris</i>
A	A1	197	97.5	1	1	0.5
B	B1	35	100	0	0	0
C	C1	58	100	0	0	0
	C2	40	100	0	0	0

^a Marks indicate each peak of the population density of the citrus red mite in Fig. 1.

Table 3. Developmental rates and periods of the indigenous population of *N. californicus*^a preying on the eggs of *P. citri* or *T. urticae*

Prey	<i>n</i>	Developmental rate (%)	Developmental period (day)		Consumptive eggs ^b (eggs)	
			Female	Male	Female	Male
<i>P. citri</i>	53	92	8.3	8.2	19.5	11.6
<i>T. urticae</i>	46	96	8.2	8.1	11.7	9.7
<i>p</i> ^c		—	0.298	0.850	0.000	0.069

^a Individual predatory mites were reared on a leaf disk of Satsuma mandarin, kidney bean, with 30 eggs of *P. citri*, *T. urticae*, respectively.

^b The number of prey eggs consumed by phytoseiid mites until the day of emergence.

^c Numbers indicate probabilities by *t* test.

T. urticae eggs.

From the third to the eighth day after emergence, the daily fecundity of adult females did not differ between the species of the prey eggs (Table 4). On the other hand, the number of *P. citri* eggs consumed daily was greater than that of *T. urticae* eggs for that period.

DISCUSSION

In this survey, the natural enemies of the citrus red mite were prevalent when the population of spider mites peaked once or twice from June to September in commercial Satsuma mandarin groves. The natural enemies mainly comprised phytoseiid mites among which *N. californicus* was predominant (Fig. 1; Tables 1 and 2) in Mikkabi, Shizuoka Prefecture. Previous studies have demonstrated that the phytoseiid mite species known to prey on the citrus red mite in the citrus groves in Japan include *Amblyseius eharai*, *T. vulgaris*, and *E. sojaensis* (Mori, 1964; Tanaka and Inoue, 1973; Nakao, 1977; Osakabe et al., 1987). *N. californicus* is

Table 4. Daily prey egg consumption and fecundity of adult females^a of *N. californicus* preying on eggs of *P. citri* or *T. urticae*

Prey	<i>n</i>	Daily consumption ^b (eggs)	Daily fecundity ^c (eggs)
<i>P. citri</i>	9	17.2	2.5
<i>T. urticae</i>	11	11.7	2.5
<i>p</i> ^d		0.000	0.505

^a Adult females grew to prey on eggs of the same species and coupled for two days after emergence.

^b Mean numbers of eggs of prey mites consumed by individual adult females of phytoseiid mites from 3rd to 8th day after emergence.

^c Mean number of eggs laid by individual adult females of phytoseiid mites in the same period.

^d Numbers indicate probabilities by *t* test.

known to be a cosmopolitan mite in the subtropical and temperate regions and is found in South America, southern Europe, and California (McMurtry and Croft, 1997). In Japan, a recent increase was observed in the distribution of *N. californicus* on

many host plants that have been infected by *Tetranychus* prey mites since the late 1980s (Amano, 2001); however, the occurrence of this phytoseiid mite on citrus trees in Japan has not yet been reported.

N. californicus is considered to be one of the most prospective phytoseiid mites for the suppression of spider mites. It plays a role in conservation strategies for various crops such as grapes, apples, and citrus fruits in California and Chile (McMurtry and Croft, 1997). On the other hand, there have been reports on the effects of the release of *N. californicus* for controlling *T. urticae* on strawberry (Oatman et al., 1977) and *Oligonychus protensis* on corn (Pickett and Gilstrap, 1986). Kishimoto (2002) revealed that the population dynamics of *N. californicus* was synchronized with *T. urticae* or *P. citri* found on Japanese pear trees in orchards. Our survey detected that the occurrence of *N. californicus* was synchronous with the population dynamics of *P. citri* on Satsuma mandarin trees in commercial groves (Fig. 1). Since these groves were not applied with chemicals to control spider mites from late April to mid-September, and other natural enemies occurred slightly, it is supposed that populations of citrus red mites were suppressed mainly by the predation of *N. californicus*.

N. californicus belongs to type II selective predators of tetranychid mites, classified based on their food habits by McMurtry and Croft (1997). The species in type II show a broader range of prey on which they thrive in addition to Tetranychidae than type I, represented by *Phytoseiulus* species which are specialized predators of *Tetranychus* species. Some studies were conducted to study the oviposition of *N. californicus* that prey on several tetranychid mite species. Croft et al. (1998) indicated that fecundity decreased significantly in the following order: *T. urticae*, *P. ulmi*, and *Oligonychus ilicis*. Miya et al. (2004) indicated that a *N. californicus* population caught on *Akebia quinata* in Ibaraki Prefecture showed a few differences in fecundity and no difference in consumption by preying on eggs of *T. urticae* and *P. mori*. Our study indicates that an indigenous population caught on Satsuma mandarin trees in Shizuoka Prefecture can grow and oviposit by preying on *P. citri* eggs no less than *T. urticae* (Tables 3 and 4). It was also detected that immature and adult mites can prey equally or more on *P. citri* eggs as compared to on

T. urticae eggs. Furthermore, Toyoshima and Hinomoto (2004) indicated that the three populations of *N. californicus* caught Japanese pear trees in Chiba and Nagano Prefectures had the following characteristics with regard to preying on *T. urticae* eggs: developmental rate, 0.800–0.891; developmental period of the female, 8.3–8.7 days; maximum daily fecundity, 2.0–2.3 eggs; and daily prey consumption at peak fecundity, 11.4–12.2 eggs. Most of these characteristics agree with the results of this study.

In conclusion, indigenous populations of *N. californicus* occur on citrus groves sprayed with conventional pesticides in central Japan and have the ability to suppress *P. citri* populations on Satsuma mandarin trees. In order to maintain a low population density of *P. citri* in the citrus groves, it is necessary to conduct further studies to improve the conservation strategies for this predator; these strategies may include the selection of uninfluenced pesticides and the development of other habitats in groves.

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