Life-history traits of the Kanzawa spider mite *Tetranychus kanzawai* (Acari: Tetranychidae)

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(Received 5 July 2002; Accepted 2 September 2002)

Abstract

Life-history traits of the Kanzawa spider mite, *Tetranychus kanzawai*, were assessed and compared with those of the closely related species, *T. parakanzawai*. This was done by determining the intrinsic rates of natural increase, r_m , of three strains of *T. kanzawai* and one strain of *T. parakanzawai*, on leaf discs from each of the four host plants (collected plants) as well as one of suitable hosts for *T. kanzawai*, mulberry. The r_m -values of the three *T. kanzawai* strains varied largely from 0.187/day to 0.283/day, and the r_m 's on the collected hosts (tea, hydrangea and Japanese pear) were 0.043–0.096/day lower than on mulberry. The r_m of the *T. parakanzawai* strain was only 0.008/day lower on the collected plant (kudzu vine) than on mulberry. These results seem to suggest that tea, hydrangea and Japanese pear are poor-quality plants for *T. kanzawai* when compared to their performance on mulberry.

Key words: *Tetranychus kanzawai*; *Tetranychus parakanzawai*; intrinsic rate of natural increase; tea; host plant

INTRODUCTION

Performance of phytophagous insects and spider mites on different host plants is influenced by the nutritional value and defenses of the plants; important factors include secondary chemicals, leaf nutrition, leaf age and leaf surface structure (Gerson and Aronowitz, 1980; Jaenike, 1990; Wilson, 1994; Van Impe and Hance, 1993; Krips et al., 1998; Agrawal, 2000). When spider mites infest chemically defended or poor-quality plants, their intrinsic rate of natural increase (r_m) should be low (Gould, 1979; Fry, 1989; Bruin et al., 1992; Krips et al., 1998; Agrawal, 2000). In the two-spotted spider mite, *Tetranychus urticae* Koch, for example, the initial r_m -value (0.088/day) on a resistant gerbera cultivar was increased to 0.208/day after they had been reared on this cultivar for five months, but it was still substantially lower than the r_m -value on a susceptible cultivar (0.242/day; Krips et al., 1998). Adaptation of mites to unsuitable host plants or novel host plants that are of poor quality is often accompanied by a reduction in fitness, even if the mites are polyphagous.

The Kanzawa spider mite, *Tetranychus kanzawai* Kishida, is an important pest threatening many agricultural crops and ornamental plants in Far

Eastern areas. The broad host range of *T. kanzawai* is due to the presence of host races: the ability to develop on tea, *Camellia sinensis* L., and hydrangea, *Hydrangea macrophylla* (Thunb.), containing harmful secondary chemicals for spider mites is regulated by a single dominant gene, 'T' and 'H', respectively (Gomi and Gotoh, 1996, 1997). These genes are thought to be involved in the chemical detoxification of harmful secondary chemicals, such as tannin in tea and hydrangenol in hydrangea (Dowd et al., 1983; Ujihara et al., 1995; Gomi and Gotoh, 1997; Gotoh and Gomi, 2000). Recently, *T. parakanzawai* Ehara, a sibling species of *T. kanzawai*, is found on the kudzu vine, *Pueraria lobata* (Willd.) (Ehara, 1999). The host range of this species overlaps considerably with that of *T. kanzawai* (Gomi and Gotoh, 1996), but *T. parakanzawai* never develops on tea or on hydrangea (Gotoh et al., 1999). For effective management of *T. kanzawai*, we need to know its ecological traits (population growth rate, etc.) on economically important plants. Most of the data obtained thus far are on easily grown host plants such as bean, while few are on crops such as grape (Kondo et al., 1987). The difference of the r_m -values among the infested plants affects the actual rates of population growth, that is, how rapid a population increases on

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an infested plant.

The objective of this study was to determine whether plants with known presence of harmful secondary chemicals affect the life-history traits of *T. kanzawai*. We compared the r_m -values of mites, reared on the host plants on which they had been collected in the field (collected host), to those of mites on mulberry, considered a suitable host of *T. kanzawai* (Gomi and Gotoh, 1996). In addition, the r_m -values of *T. kanzawai* were compared to those of *T. parakanzawai*, which could develop on neither tea nor hydrangea.

MATERIALS AND METHODS

The strains of *T. kanzawai* and *T. parakanzawai* used in this study are summarized in Table 1. These are the same strains that have been studied by Gomi and Gotoh (1996, 1997) and Gotoh et al. (1999). Each strain was maintained on leaf discs (ca. 25 cm²) of each host plant where the mites were collected (collected host), placed on a water-saturated polyurethane mat in a plastic dish (9 cm in diam.) at 25°C and 16L:8D. In winter, when hydrangea, Japanese pear (*Pyrus pyrifolia* (Burm.)) and kudzu vine (*Pueraria lobata* (Willd.)) leaves are not available because of complete defoliation, the strains collected from these hosts were reared on kidney bean (*Phaseolus vulgaris* L.). This is because all experiments were carried out between late July and late September in 1994.

To determine the developmental time, twenty females and five males from each stock culture were introduced onto a leaf disc and allowed to lay eggs for a 24-h period. Eggs laid were singly transferred and reared on a fresh leaf disc (ca. 4 cm²), and the developmental stages were recorded daily. When a female deutonymph emerged, one adult male obtained from a stock culture was introduced onto the leaf disc for mating and then removed 24 h after emergence of the adult female. The number of eggs

laid by the females was recorded daily until they died. Plants examined in this study were tea, hydrangea, Japanese pear and kudzu vine as plants from which mite strains were initially collected, and mulberry as plant, known to suit *T. kanzawai* and *T. parakanzawai* (Gomi and Gotoh, 1996).

To assess the sex ratio (% females) of the offspring, one teleiochrysalis female and one adult male were placed on a leaf disc for copulation, and the females were allowed to lay eggs for five days after the preoviposition period. The eggs obtained from each female were cultured to determine their hatchability, survival rate in immature stages and sex ratio of the emerging mites, after reaching adulthood. Plants examined were the same as mentioned above.

The intrinsic rate of natural increase, r_m , and other parameters were calculated according to the equations given by Birch (1948). Further details are described in Gotoh (1986). The parameters were calculated for strains reared on the collected plants and mulberry.

RESULTS

Development

The total developmental times from egg to adult in the four strains were 9.3–12.2 days and 8.6–11.6 days for females and males, respectively (Table 2). The tea strain reared on tea showed the longest developmental time, followed by the pear strain on pear. The developmental times of these two strains reared on the collected plants were significantly longer than those on mulberry ($p < 0.05$, Student-Newman-Keuls test). For other strains, the times on the collected hosts were similar to those on mulberry ($p > 0.05$).

Hatchability ranged from 94.9 to 99.6% and sex ratio (proportion daughters) from 77.6 to 84.9% (Table 3). There appeared to be no significant differences between strains or host plants.

Table 1. Collection data of *Tetranychus kanzawai* (Tk) and *T. parakanzawai* (Tp) used in this study

Strain (Species)	Host plant	City, Prefecture	Geographic coordinates	Date
Tea (Tk)	<i>Camellia sinensis</i>	Kanaya, Shizuoka	34°48'N–138°23'E	May 19, 1993
Hydrangea (Tk)	<i>Hydrangea macrophylla</i>	Tsukuba, Ibaraki	36°13'N–140°04'E	March 29, 1993
Japanese pear (Tk)	<i>Pyrus pyrifolia</i>	Yachiyo, Chiba	35°55'N–140°04'E	March 16, 1993
Kudzu vine (Tp)	<i>Pueraria lobata</i>	Ami, Ibaraki	36°00'N–140°11'E	June 5, 1993

Table 2. Developmental time (in days) of immatures in *T. kanzawai* (Tk) and *T. parakanzawai* (Tp) reared on collected host plants and mulberry at 25°C and a 16L:8D photoperiod

Strain (Species)	Sex	N ^a	Egg	Larva	Protochrysalis	Protonymph	Deutochrysalis	Deutonymph	Teleiochrysalis	Total	F vs M ^b (p)
On collected host plant											
Tea (Tk)	F	29	5.1±0.08 a	1.9±0.12 b	0.6±0.12 abc	1.6±0.09 c	0.3±0.09 abc	1.7±0.09 d	0.9±0.07 ab	12.2±0.13 f	0.004
	M	34	5.0±0.07 a	1.8±0.11 b	0.7±0.09 abc	1.5±0.10 bc	0.5±0.09 abc	1.4±0.08 cd	0.8±0.08 ab	11.6±0.18 ef	
Hydrangea (Tk)	F	35	4.9±0.08 a	1.0±0.00 a	0.3±0.08 abc	0.7±0.08 a	0.7±0.08 abc	1.0±0.05 bc	1.0±0.00 ab	9.7±0.10 bc	0.004
	M	18	5.2±0.12 a	1.0±0.00 a	0.2±0.09 ab	0.8±0.09 a	0.7±0.11 abc	0.3±0.11 a	1.0±0.00 ab	9.2±0.12 abc	
Japanese pear (Tk)	F	36	4.8±0.06 a	1.1±0.04 a	0.8±0.07 c	1.0±0.06 ab	0.9±0.05 bc	1.0±0.03 bc	1.2±0.07 b	10.8±0.12 de	<0.001
	M	23	4.9±0.13 a	1.1±0.06 a	0.6±0.12 abc	0.8±0.08 a	0.3±0.10 abc	1.0±0.08 bc	1.0±0.06 ab	9.7±0.23 bc	
Kudzu vine (Tp)	F	39	4.7±0.09 a	1.0±0.03 a	0.8±0.07 bc	0.8±0.06 a	0.6±0.08 abc	0.8±0.07 ab	1.1±0.04 ab	9.9±0.09 cd	0.003
	M	20	5.0±0.05 a	1.0±0.00 a	0.4±0.11 abc	0.8±0.10 a	1.0±0.05 c	0.4±0.11 a	1.0±0.00 ab	9.4±0.13 abc	
On mulberry											
Tea (Tk)	F	36	4.9±0.07 a	1.0±0.00 a	0.2±0.06 ab	0.8±0.06 a	0.4±0.08 abc	1.0±0.04 bc	1.0±0.03 ab	9.3±0.13 abc	0.016
	M	17	5.1±0.12 a	1.0±0.00 a	0.2±0.11 abc	0.8±0.11 a	0.3±0.11 ab	0.6±0.12 ab	0.8±0.10 ab	8.8±0.10 ab	
Hydrangea (Tk)	F	32	4.9±0.09 a	1.0±0.00 a	0.2±0.07 abc	0.8±0.07 a	0.5±0.09 abc	1.0±0.03 bc	1.0±0.00 ab	9.4±0.11 abc	<0.001
	M	21	5.1±0.08 a	1.0±0.00 a	0.3±0.10 abc	0.6±0.11 a	0.2±0.10 a	0.7±0.10 ab	0.8±0.09 ab	8.6±0.11 a	
Japanese pear (Tk)	F	33	5.2±0.10 a	1.0±0.00 a	0.2±0.07 abc	0.8±0.07 a	0.5±0.09 abc	0.9±0.06 bc	1.0±0.00 ab	9.6±0.11 abc	<0.001
	M	17	4.8±0.16 a	1.0±0.00 a	0.2±0.10 abc	0.8±0.10 a	0.2±0.10 a	0.8±0.10 abc	0.8±0.11 a	8.6±0.17 a	
Kudzu vine (Tp)	F	34	4.9±0.09 a	1.0±0.00 a	0.1±0.06 a	0.9±0.06 a	0.5±0.09 abc	0.9±0.06 bc	1.0±0.00 ab	9.3±0.14 abc	0.005
	M	19	5.2±0.12 a	1.0±0.00 a	0.2±0.09 a	0.8±0.09 a	0.3±0.10 a	0.5±0.12 ab	0.8±0.10 ab	8.7±0.10 ab	
χ ² -value ^c			33.90**	276.88***	107.87***	125.30***	80.75***	178.56***	61.45***	266.15***	

^a Number of individuals tested.

^b Intersexual difference in total developmental time was tested by Mann-Whitney U-test.

^c Means differ significantly at $p < 0.01$ (**) and $p < 0.001$ (***) (Kruskal-Wallis test); ns, not significant at $p > 0.05$. Data are shown as mean ± SE. Values in a column followed by different letters are significantly different at $p < 0.05$ (Scheffé's test).

Table 3. Hatchability of eggs laid during the first 5 days of the oviposition period, survival rate of immature stages and the proportion of females reaching adulthood in *T. kanzawai* (Tk) and *T. parakanzawai* (Tp) reared on collected hosts and mulberry at 25°C and 16L:8D a photoperiod

Strain	N ^a	No. of eggs/female	Hatchability (%)	Survival rate in immatures (%)	Proportion of females (%)
On collected host plant					
Tea (Tk)	22	21.5±1.27 a	97.0±0.72 ab	99.0±0.45 a	77.6±1.49 a
Hydrangea (Tk)	27	21.2±0.90 a	95.8±0.97 ab	96.7±0.87 a	83.9±1.04 b
Japanese pear (Tk)	14	37.4±1.28 b	99.6±0.26 b	98.0±0.57 a	84.9±0.82 b
Kudzu vine (Tp)	18	48.2±1.40 d	98.4±0.36 ab	99.1±0.33 a	78.0±1.09 a
On mulberry					
Tea (Tk)	23	41.0±1.19 bc	94.9±1.29 a	96.1±0.77 a	80.8±1.04 ab
Hydrangea (Tk)	20	38.8±0.77 bc	98.3±0.52 ab	98.6±0.38 a	78.2±0.54 a
Japanese pear (Tk)	28	44.5±1.14 cd	99.5±0.30 b	98.2±0.47 a	84.8±0.58 b
Kudzu vine (Tp)	34	43.9±1.22 bcd	99.2±0.36 b	97.8±0.65 a	82.7±0.46 ab
χ^2 -value ^b		124.29***	28.28***	15.33*	57.16***

^a Number of females tested.

^b Means differ significantly at $p<0.05$ (*) and $p<0.001$ (***) (Kruskal-Wallis test). Data are shown as mean±SE. Values in a column followed by different letters are significantly different at $p<0.05$ (Scheffé's test).

Oviposition

Age at first oviposition in the tea strain on tea and the pear strain on pear was later than on mulberry ($p<0.05$, Scheffé's test; Table 4). In the other two strains, first oviposition occurred at 11–12 days and did not differ between the collected hosts and mulberry.

Total number of eggs per female in the tea strain on tea and the hydrangea strain on hydrangea was significantly lower than on mulberry (Table 4). The number of eggs per female per day in the tea, hydrangea and pear strains was higher on mulberry than on the collected hosts ($p<0.05$). Oviposition period and total adult longevity were almost as high on the collected host as on mulberry.

On the other hand, the total number of eggs laid in the kudzu vine strain of *T. parakanzawai* was significantly higher on the collected host than on mulberry. The number of eggs laid per female per day in the kudzu vine strain was the same for both the collected hosts and mulberry ($p>0.05$). The oviposition period was significantly shorter on mulberry than on the original host ($p<0.05$). Likewise, total adult longevity was shorter in the kudzu vine strain on mulberry.

Figure 1 shows l_x (age-specific survival rate×egg hatchability), m_x (age-specific oviposition rate×proportion of females) and $l_x m_x$ (the expected number of female offspring at age x) curves in *T.*

kanzawai and *T. parakanzawai* at 25°C. On the collected hosts, the daily egg production reached a peak of 4.2 eggs on day 16, 4.9 eggs on day 14, 6.3 eggs on day 17 and 12.0 eggs on day 14 in the tea, hydrangea, pear and kudzu vine strains, respectively. On mulberry, on the other hand, the oviposition rate peaked at 10.6 eggs on day 13, 10.3 eggs on day 15, 10.6 eggs on day 14 and 11.3 eggs on day 15 in the tea, hydrangea, pear and kudzu vine strains, respectively. Female adults started to die on the collected hosts on day 24, 21, 26 and 24 in the tea, hydrangea, pear and kudzu vine strains, respectively. On mulberry, survival of the female adults began to decrease on day 23, 24, 22 and 23 in the respective strains.

Rate of population increase

The net reproductive rate (R_0), intrinsic rate of natural increase (r_m , day⁻¹), mean generation time (T , in days), finite rate of increase (λ), and doubling time (D) in the four strains are given in Table 5. The R_0 -values on the collected hosts were lower than those on mulberry except for the kudzu vine strain, whose R_0 -value was higher on the collected plant than on mulberry. The r_m - and λ -values were higher on mulberry than on the collected hosts for all four strains. Mean generation times were higher on the collected plant than on mulberry, except the hydrangea strain showing similar values on the two

Table 4. Ovipositional rate and various durations of adult stage in *T. kanzawai* (Tk) and *T. parakanzawai* (Tp) reared on collected host plants and mulberry at 25°C and a 16L:8D photoperiod

Strain	N ^a	Age at first oviposition	No. of eggs/female	No. of eggs/female/day	Preoviposition period (days)	Oviposition period (days)	Postoviposition period (days)	Total adult longevity (days)
On collected host plant								
Tea (Tk)	29	14.4±0.20 d	45.3±3.70 a	2.8±0.19 a	1.4±0.14 bc	16.2±0.72 a	1.1±0.17 a	18.7±0.68 a
Hydrangea (Tk)	26	12.3±0.18 bc	55.1±3.77 a	2.8±0.17 a	1.7±0.15 c	21.3±1.64 ab	1.5±0.18 a	24.1±1.54 bc
Japanese pear (Tk)	32	13.1±0.14 c	84.3±4.46 b	4.5±0.15 b	1.3±0.09 abc	18.9±0.81 ab	0.7±0.19 a	20.9±0.86 ab
Kudzu vine (Tp)	24	11.8±0.12 ab	175.6±9.18 d	7.5±0.26 d	1.1±0.08 ab	23.8±1.20 b	1.5±0.26 a	26.3±1.18 c
On mulberry								
Tea (Tk)	29	11.0±0.17 a	84.4±2.68 b	4.4±0.18 b	0.8±0.09 a	19.8±0.64 ab	1.5±0.21 a	22.2±0.78 abc
Hydrangea (Tk)	32	11.7±0.13 ab	122.2±6.74 c	5.9±0.17 c	1.3±0.08 abc	21.0±1.01 ab	1.2±0.16 a	23.5±1.02 abc
Japanese pear (Tk)	33	11.5±0.12 ab	95.1±3.91 bc	5.6±0.17 c	0.9±0.04 ab	17.2±0.76 a	1.6±0.10 a	19.8±0.77 ab
Kudzu vine (Tp)	32	11.6±0.16 ab	123.1±5.55 c	7.5±0.23 d	1.2±0.08 abc	16.7±0.73 a	1.6±0.14 a	19.5±0.72 ab
χ^2 -value ^b		129.38***	153.61***	176.29***	44.65***	40.32***	22.93**	39.76***

^aNumber of females tested.

^bMeans differ significantly at $p<0.01$ (**) and $p<0.001$ (***) (Kruskal-Wallis test). Data are shown as mean±SE. Values in a column followed by different letters are significantly different at $p<0.05$ (Scheffé's test).

Fig. 1. The age-specific survival rate (l_x), age-specific fecundity rate (m_x) and $l_x m_x$ curves in *T. kanzawai* and *T. parakanzawai* strains at 25°C and 16L:8D. l_x =(proportion of females alive at age x)×(egg hatchability), m_x =(age-specific oviposition)×(proportion of females).

plants. On the collected hosts, doubling times decreased in the order of tea>hydrangea>pear>kudzu vine strains, but on mulberry they remained more or less the same.

DISCUSSION

The present study showed that some plants have significantly adverse effects on development and reproduction of *T. kanzawai*. Large differences in the r_m -values of *T. kanzawai* were found, ranging from 0.187/day in the tea strain on tea to 0.283/day in the tea and pear strains on mulberry. Although we used strains reared on their collected host plants for three months (May–July 1994) or one year (tea strain; May 1993–July 1994), the r_m -values on the collected hosts were 0.043–0.096/day lower than those on mulberry. It seems it is not only harmful secondary chemicals in tea and hydrangea leaves

Table 5. Parameters related to potential rates of population increase in *T. kanzawai* (Tk) and *T. parakanzawai* (Tp) reared on collected host plant and mulberry at 25°C and 16L:8D photoperiod

Strain	N^a	Net reproductive rate, R_0	Intrinsic rate of natural increase, r_m , day ⁻¹	Mean generation time, T , in days	Finite rate of increase, λ	Doubling time, D
On collected host plant						
Tea (Tk)	29	34.11	0.187	20.46	1.205	3.707
Hydrangea (Tk)	26	44.27	0.224	19.65	1.251	3.094
Japanese pear (Tk)	32	71.24	0.229	21.25	1.258	3.027
Kudzu vine (Tp)	24	134.80	0.276	22.17	1.318	2.511
On mulberry						
Tea (Tk)	29	64.70	0.283	16.51	1.326	2.449
Hydrangea (Tk)	32	93.93	0.267	19.81	1.307	2.596
Japanese pear (Tk)	33	80.26	0.283	17.61	1.328	2.449
Kudzu vine (Tp)	32	101.01	0.284	18.44	1.329	2.441

^a Number of females tested.

that affect life-history parameters of *T. kanzawai*, but also that Japanese pear is of poor quality to the mite. Nevertheless, for the tea strain reared on tea leaves during the subsequent one year or more after collection, the r_m -value remained 0.187/day, which was still 0.096/day lower than that on mulberry. This suggests that the initial r_m -value, which is examined just after collection, will be lower than this value. We need to clarify how the r_m -values change with the number of generations after collection.

Sabelis (1985, 1991) gives an extensive review of life-history parameters of tetranychid mites. For *Tetranychus* mites, he found the r_m -values to range from 0.200 to 0.336/day at around 25°C. The r_m -values of *T. kanzawai* and *T. parakanzawai* fall within this range, except for the tea strain on tea (0.187/day). The r_m of the hydrangea strain on mulberry was comparable to the previously reported value (0.268/day) of *T. kanzawai* on bean (Kondo and Takafuji, 1985), but other strains on mulberry had slightly higher r_m -values than the hydrangea and bean strains. Similar examples of varying r_m -values among plants are known in the citrus red mite, *Panonychus citri* (McGregor), *Tetranychus pacificus* McGregor and *T. urticae*. Two *Tetranychus* species displayed a lower r_m when reared on cotton compared to bean (Takafuji and Chant, 1976; Carey and Bradley, 1982; Sabelis, 1991). Gerson and Aronowitz (1980) showed that the r_m -values of *T. urticae* (called *T. cinnabarinus* (Boisduval) in that paper) reared on seven different plants varied from 0.091 (Algerian ivy) to 0.270

(bean). The r_m of *P. citri* was lower on citrus leaf than on pear and peach leaves (Furuhashi and Nishino, 1979). These studies show that spider mites exhibit the capacity to adapt to unsuitable or poor-quality plants but the r_m -values remained at the lower level on them, although given enough time, the r_m may grow to some extent. It seems likely that *T. kanzawai* is implicitly adapting to these plants, if we consider its propensity for rapid development of resistance to various kinds of acaricides (e.g., Goka, 1998).

The two parameters of paramount importance in determining the r_m -value are developmental time and ovipositional rate (Snell, 1978; Wrensch, 1985). For the r_m of spider mites, changes in developmental time are more important than similar changes in ovipositional rate (Sabelis, 1985). In the present study, the tea strain on tea and the hydrangea strain on hydrangea showed similar ovipositional rates (Table 3), but developmental time in the tea strain was 2.5 days longer than that in the hydrangea strain (Table 2). As a result, the r_m -value in the former was 0.037/day lower than that in the latter. Since the developmental time among strains was similar (except for the tea strain), the difference among r_m -values assessed on the collected host plants and mulberry is attributed to the difference in ovipositional rate. The hydrangea strain, for example, displayed a higher r_m -value on mulberry than on hydrangea, because the peak ovipositional rate differed greatly: on mulberry it was 10.3 eggs on day 15, whereas on hydrangea it was 4.9 eggs

on day 14.

Rodriguez et al. (1983) showed that the density of *T. urticae* was higher on young soybean leaves than on old leaves. The tea strain on tea showed the lowest r_m -value in the present study. We used mature leaves of tea plant for rearing this strain, but we should test the r_m -value on young leaves, because the absolute r_m -value on tea may become higher than in this study, as shown in *T. urticae*. However, it is difficult to test this possibility, because leaf discs made of young leaves promptly deteriorated and could not maintain leaf quality throughout the experimental periods. The relationship between leaf age of tea and developmental performance of mites remains to be clarified.

The r_m -values of *T. kanzawai* differed significantly among the plants tested. This seems to be attributable to differences in the adaptation degrees to host-plant resistance and/or nutritional quality of the hosts. Hence, the r_m -values of economically important mites should be determined on the crop plants they attack, rather than on easily grown plants such as bean, especially when one's aim is to control these mites.

ACKNOWLEDGEMENTS

We are indebted to J. Bruin, University of Amsterdam, for invaluable comments, and to S. Yano, Kyoto University, for his kind suggestions.

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