Ovipositional Behaviour of Diapause-Induced Females of
the Citrus Red Mite, *Panonychus citri* (McGREGOR)
(Acarina: Tetranychidae)¹

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Ovipositional behaviour of diapause-induced females (winter females) of a diapausing strain of *Panonychus citri* (McGREGOR) was studied in comparison with that of non-diapause-induced females (summer females). Winter females were very active during the first 2 to 3 days after adult emergence, showing a remarkable increase in walking time. This increase was well synchronized with egg maturation in ovary. Summer females did not show any such increase. Winter females spent more than twice as long the time to deposit an egg on pear twigs as the summer females on leaves. The former spent much longer time for locating a suitable oviposition site and for returning from the site to leaf. Winter females always returned to leaves after depositing only a single egg.

INTRODUCTION

As in many insects, diapause and non-diapause forms of spider mites may have different colouration, morphology, physiology and behaviour (see the review by VEERMAN, 1985). Only a few studies have so far been reported on the behavioural aspects of spider mites, such as the two-spotted spider mite, *Tetranychus urticae* KOCH with a reproductive diapause (FOOTT, 1965; BONDARENKO, 1958; HUSSEY and PARR, 1963) and the European red mite, *Panonychus ulmi* KOCH with an embryonic diapause (LEES, 1953).

Diapausing strain of the citrus red mite, *Panonychus citri* (McGREGOR) occurs on deciduous fruit trees such as pear and peach at intermediate and higher latitudes of Japan (SHINKAJI, 1961a, 1979). Populations of this strain have a number of generations a year and females lay diapausing eggs on twigs of deciduous trees in autumn. Field observations show that diapause-induced females move actively from leaves to twigs of deciduous trees for oviposition in autumn (UCHIDA and SHINKAJI, 1980). Similar behaviour has been observed in *P. ulmi* (LEES, 1953).

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FUJIMOTO and TAKAFUJI (1988) showed that diapause-induced females often fail to lay eggs if they were artificially confined on pear leaf discs or on leaf discs with a small piece of pear twig on them as oviposition sites. However they successfully lay eggs on detached pear twig with leaves. No detailed study has so far been done on the ovipositional behaviour of diapause-induced females of tetranychid mites with an embryonic diapause, such as *P. citri*.

This study was, therefore, undertaken to examine the ovipositional behaviour of diapause-induced females of a diapausing strain of *P. citri* in comparison with that of non-diapause-induced females (which lay non-diapausing eggs), thereby elucidating the behavioural properties leading to the deposition of diapausing eggs.

MATERIALS AND METHODS

Population. The population used in this study was collected as overwintering eggs from Japanese pear at Amagi, Fukuoka Prefecture in northern Kyusyu ($33^{\circ}17' N$) in February, 1985. It had been cultured for about 2 months on Japanese pear leaf discs at $25^{\circ}C$, 16L-8D prior to experiments. The pear leaves were taken from trees grown under outdoor conditions. This population is a diapausing strain with a critical day-length of about 13 hr at $20^{\circ}C$. All females were induced to lay diapausing eggs if they were exposed to photoperiods of less than 12 hr during development. When developed at photoperiods of more than 14 hr, all females laid non-diapausing eggs (FUJIMOTO and TAKAFUJI, 1986, 1988). Females used in the following experiments were diapause-induced (winter females) or non-diapause-induced (summer females) by rearing them from eggs to adults under 12L-12D or 16L-8D at $20^{\circ}C$, respectively.

Change in walking activity of diapause-induced females during egg maturation. As stated, winter females have been observed to move actively on twigs, which suggests that a drastic behavioural change may have occurred. To clarify this, walking activity of winter females was studied in comparison with that of the summer females. Females of each of the two forms were introduced individually onto 4×2 cm² pear leaf discs within 24 hr after emergence. At 24, 48 and 72 hr after introduction, time spent for walking by the females was recorded during a 100-minute observation period. In addition, some extra winter females were dissected at each observation time to determine when eggs matured. Such procedure was necessary because they normally do not lay eggs on leaf discs (FUJIMOTO and TAKAFUJI, 1988).

Ovipositional behaviour. Summer females were individually introduced onto 4×2 cm² pear leaf discs, whereas 1 to 3 winter females were introduced onto a 5-10 cm pear twig, with 1 to 3 leaves, kept in a water-filled test tube. Both females were from 3 to 10 days postmaturation. A ring of vaseline was applied around the bottom of the twig to prevent the mites from escaping. Observations were made from the start of walking on a leaf (or a leaf disc) to oviposition site to settling on a leaf (or a leaf disc) after oviposition, using a $16 \times$ magnifying lens. Time spent for various activities in the process of oviposition was recorded in minute.

All experiments were conducted under the same condition in which females had developed.

RESULTS

Change in walking activity during egg maturation

Figure 1A shows average walking time per 100-minute observation of the two forms of female during the first 3 days after emergence. Average walking time of winter females increased markedly from 7.4 to 45.7 min during that period. It was highly significantly ($p < 0.001$, t -test) longer than that of the summer females (2–4 min) on days 2 and 3. The longer walking time of winter females was the result of both longer duration of each walking and more frequent walking (Table 1).

The proportion of winter females with mature ova increased sharply from nil on

Fig. 1. (A) Change in time spent walking (min) by summer and winter females of *P. citri* during a 100-min observation. (B) Proportion of winter females with mature ova. Each point is the average from 23 to 67 females. Vertical lines indicate S.E.

Table 1. Change in walking activity of summer and winter females of *P. citri* in the first 3 days after adult emergence

Days after emergence	Summer females	Winter females
Duration of movement (min)*		
1	5.3 ± 3.9 (21)	10.6 ± 6.8 (42)
2	7.1 ± 5.8 (15)	14.5 ± 13.5 (127)
3	3.9 ± 2.6 (13)	19.6 ± 19.8 (100)
No. of movements per female**		
1	0.64 (33)	0.70 (60)
2	0.50 (30)	1.90 (67)
3	0.57 (23)	2.33 (43)

* Mean ± S.D. (n)

** Mean (n)

The duration of each movement and the number of movements were recorded during 100-min observations.

the first day to about 95% on the 3rd day (Fig. 1B). This increase was synchronized with the increase in the walking activity of the females, showing that winter females developed mature ova normally even on leaf discs as did summer females.

Ovipositional behaviour

Figure 2 shows several typical examples of ovipositional behaviour of the two forms of female. It consisted basically of 4 sequential activities: searching for an oviposition site (A), deposition of an egg (B), covering the egg with silken threads (C), and leaving the oviposition site and returning to feeding site (D). It is interesting to note that females always deposited only a single egg during the course of sequential activities.

Significant differences were observed in each of the activities between the two forms (Table 2). Winter females spent 3.4 times longer for searching an oviposition site than the summer females ($p < 0.001$, t -test). Great variations in searching time in winter females were observed (Table 2). They walked rapidly from leaf to twig, mainly along the vein or edge of the leaf and moved rapidly up and/or down the twig. Once the females reached an area near a dormant bud, they suddenly slowed down and finally ceased and deposited an egg.

Summer females spent significantly ($p < 0.001$) longer time for egg deposition than winter females. However, winter females spent a significantly ($p < 0.001$) longer time for webbing (Table 2).

Fig. 2. Examples showing movement patterns involved in oviposition of summer and winter females of *P. citri*. The movement patterns of winter females on a leaf (upper), a petiole (middle), and a twig (lower) were illustrated.

Table 2. Activities associated with oviposition of summer and winter females of *P. citri*

Activities		Length of time spent (min)	
		Summer females	Winter females
Searching for an oviposition site	(A)	6.7±4.3 (25)*	22.6±13.8 (29)
Egg deposition	(B)	18.3±2.5 (25)	13.9± 1.3 (33)
Webbing silken threads	(C)	1.3±0.6 (29)	3.4± 1.3 (33)
Returning to feeding site after oviposition	(D)	1.1±1.1 (29)	33.1±50.5 (28)
A+B+C+D		28.1±5.5 (22)	67.5±46.7 (25)

* Mean±S.D. (n).

The average time spent for returning to feeding site after oviposition differed greatly between the two forms, being 1.1 and 33.1 min in summer and winter females respectively (Table 2). Winter females exhibited 3 different patterns in this activity (Fig. 2). In 17 out of the 28 females observed, they walked rapidly on twig after webbing over the egg, moved to a leaf via a petiole and settled down immediately (Pattern 1). In 7 females, they remained motionless near the oviposition site on twig for 24 to 155 min before moving back to leaf (Pattern 2). In the last 4, females laid an egg on a leaf and walked for 1 to 2 min on the leaf after oviposition (Pattern 3). They spent shorter time for (D) than those exhibited the first 2 patterns. However, there was no significant ($p>0.05$) difference among the 3 patterns in the time spent for activities (A), (B) and (C).

The total time spent for the entire oviposition activity was about 2.4 times longer in winter females than in the summer females.

DISCUSSION

This study confirms that winter females of *P. citri* move rapidly from leaf to twig when their eggs mature. This behavioural change in the diapause-induced females enables them to successfully locate oviposition sites on twigs where eggs overwinter. This is presumably based on a transient change in taxis responses such as geotaxis, phototaxis or hygrotaxis as stated in the teneral females of *T. urticae* (HUSSEY and PARR, 1963; McENROE, 1969) and the diapause-induced females of *P. ulmi* (LEES, 1953). This study also shows that the time spent searching for an oviposition site varies greatly among winter females. Apparently they do not lay eggs until they locate a suitable oviposition site near dormant buds. It seems that egg deposition is triggered mainly by the external physical structure of twigs.

Unsuccessful location of oviposition sites probably resulted in the extremely low oviposition rate observed in our previous experiment (FUJIMOTO and TAKAFUJI, 1988). It seems that the females often failed to move from leaf to the twig provided on the leaf disc. Even if they did, the absence of suitable oviposition sites on the twig without dormant buds inhibited oviposition.

The difference in the time spent depositing an egg between the two forms seems to reflect some physiological differences in the reproductive systems. In *P. ulmi*, winter

females complete the reception of an egg from the ovary into the oviduct earlier before depositing it than the summer females (BEAMENT, 1951). The longer time in webbing silken threads over eggs by winter females shows that diapausing eggs are covered with heavier silken threads, which better protect the eggs against drought and detachment in winter.

Winter females spend much longer time for the whole process of oviposition than the summer females. The former are less fecund than the latter (FUJIMOTO and TAKAFUJI, in preparation) but the winter eggs are larger (SHINKAJI, 1961b). This enables the eggs to overwinter successfully (TAKAFUJI and FUJIMOTO, 1986).

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