Comparative biology and life table of *Stethorus pauperculus* (Weise) and *S. siphonulus* Kapur (Coleoptera: Coccinellidae) fed on *Tetranychus urticae* Koch (Acari: Tetranychidae) in Thailand

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Abstract

Stethorus pauperculus (Weise) and *S. siphonulus* Kapur are common coccinellid predators feeding upon spider mites in Thailand. The life cycles and life tables of *S. pauperculus* and *S. siphonulus* were performed under laboratory conditions at 27-28°C, 70-75%RH and 12:12 L:D regimes using *Tetranychus urticae* Koch as prey. *S. pauperculus* and *S. siphonulus* required 14.05 and 11.25 days to complete their development. The highest mortality rate of both *Stethorus* beetles occurred in the first larval stage and survival rate from egg to adult was only 50.5% for *S. pauperculus* and 70.5% for *S. siphonulus.* The longevity of *S. pauperculus* male and female was significantly longer than those of *S. siphonulus.* The egg laying period of *S. pauperculus* averaged 66.81 days while 27.72 days was recorded for S. *siphonulus. S. pauperculus* laid significantly higher number of eggs (240.91 eggs female^{-1}) as compared to that of *S. siphonulus* (150.71 eggs female^{-1}). The mean generation time (T_c), net reproductive rate (R_o), the intrinsic rate of natural increase (r_m), the finite rate of increase (λ) and population doubling times (Dt) were 51.58, 71.07, 0.114, 1.120, 6.107 and 29.12, 61.73, 0.158, 1.171, 4.401 for *S. pauperculus* and *S. siphonulus*, respectively.

Keywords: predator, spider mite, coccinellid beetle, reproduction, life cycle

Introduction

Numerous species of coccinellid beetles are major biological control agents of agricultural pests such as aphids, thrips, mealybugs and spider mites in many parts of the world (Moreton, 1969). Among known species of coccinellid, the genus *Stethorus* has a worldwide distribution and is present in areas of very different climates and in many ecosystems including tropical rain forests, dry savannas, orchards and various crops (Gordon and Anderson, 1979; Houston, 1980; Guoyue, 1996; Chazeau, 1985). Approximately 90 species of *Stethorus* are known around the world (Gouyue, 1996). Many species of *Stethorus* are primary predators of spider mites (McMurtry et al., 1970; Hoy and Smith, 1982; Charles et al., 1985; Bailey and Caon, 1986), some of which have been suggested to have potential as biological control agents of spider mites in agricultural crops (Readshaw, 1975; Hull et al., 1976, 1977). Many species of *Stethorus* feed on wide range of tetranychid species while some species such as *Stethorus keralicus* Kapur and *Stethorus gilvifrons*

(Mulsant) are considered as specialists that feed upon *Raoiella macfarlanei* Pritchard and Baker and *Tetranychus urticae* Koch, respectively (Nageshchandra and ChannaBasavanna, 1983; Aydemir and Toros, 1990). At present, only *Stethorus punctillum* Weise is commercially produced as a mite predator (Copping, 2001).

To date, only 6 species of *Stethorus* have been reported in Thailand, namely *Stethorus indira* Kapur, *S. rani* Kapur, *S. siphonulus* Kapur, *S. tetranychi* Kapur, *S. vinsoni* Kapur and *S. pauperculus* (Chunram, 2002). During the preliminary survey for biological control agents of spider mites in the campus of Khon Kaen University, Northeast of Thailand, *S. pauperculus* is frequently found feeding on spider mites infesting papaya, mulberry and cassava, followed by *S. siphonulus* while *S. indica* is seldom encountered on these plants.

Puttaswamy and ChannaBasavanna (1977) reported that *S. pauperculus* feeding on spider mites infesting papaya, papaw, castor, citrus, jasmine and various crops in Bangalore, India. This particular predator is also widely distributed in Pakistan (Irshad, 2001). The first report on biology of *S. pauperculus* feeding on *Tetranychus cucurbitae* Rahman and Sapra was investigated by Puttaswamy and ChannaBasavanna (1977) in India. Few years later, Chayopituk (1983) studied the efficacy of *S. pauperculus* on controlling *Tetranychus hydrangeae* Pritchard and Baker in Thailand. *S. siphonulus* is distributed in Malaysia, Thailand and the Hawaiian Islands. Raros and Haramoto (1974) studied the biology of *S. siphonulus* fed on *Tetranychus cinnabarinus* (Boisd.) in Hawaii while Inamullah (2000) investigated the biology of *Stethorus vagans* (Blackburn) (a synonym of *S. siphonulus*) fed upon *T. urticae* in Australia. Unfortunately, information on biology of *S. indira* is still unknown.

T. urticae is a serious pest of over 200 economically important crops such as cotton, corn, cucumber, tomato, bean, pepper and strawberries (Helle and Sabelis, 1985a, 1985b). This spider mite causes an outbreak in strawberry plantings and other cash crops in the Northern part of Thailand, hence, attempt has been performed to find potential predators to control such pest. *Stethorus punctillum* and *S. nigripes* Kapur were reported as key biological control agents for *T. urticae* (Bailey et al., 1982). However, the potential of *S. pauperculus* and *S. indira* against *T. urticae* is still unknown and the key biological attributes of these 3 *Stethorus* spp. as spider mite predators have rarely been investigated. Hence, the objective of this study was to investigate the information on biology and life table of *S. pauperculus*, *S. siphonulus* and *S. indira* to be used as a biological agent against *T. urticae* in the future.

Materials and Methods

Biological Study

Stethorus pauperculatus, S. siphonulus and *S. indira* were collected from papaya and mulberry leaves at Khon Kaen University, Thailand, then transferred and reared on fresh and clean mulberry leaves infested with *T. urticae* for several generations to provide a laboratory colony. The life cycle study was performed at 27-28°C, 70-75% RH under 12:12 L:D regimes.

To obtain eggs, 20 females and 10 males were taken from each stock culture and maintained on mulberry leaflets for oviposition. After 24 h, all adults were removed from the leaflets while eggs were left for another 24 h to prevent damage due to transferring eggs to the rearing cages. Consequently, 20 eggs of each species, 2-day-old, were placed separately on damped filter paper in a plastic box of 6×9 cm. Each newly hatched larva was then transferred to a piece of mulberry leaflet laid on damped tissue paper in the plastic box (6×6 cm) and closed with a lid to prevent escape of the beetle. A hole of 1 cm in diameter was punched on one corner of plastic lid and covered with a fine net to allow ventilation. Larvae were supplied with enormous numbers of larvae and nymphs of *T. urticae* and more prey were added daily throughout the experiment. Observations were made daily until all beetles reaching adulthood. The duration for each developmental stage was recorded. The body size and head capsule of each immature stages were also measured.

Life Table Study

A cohort of 200 eggs of each *Stethorus* spp. were used to start the life table study under laboratory conditions at 27-28°C, 70-75% RH, 12:12 L:D regimes. All eggs of the same age were confined on the mulberry leaflet laid on damped

filter paper in the rearing box covered with plastic lid as mentioned earlier. The data on egg hatching and number of individuals surviving at each stage until all adults emerged were recorded daily. Each female was kept separately on the fresh mulberry leaflet where a male was provided to facilitate fertilization. The data on number of eggs d^{-1} and number of eggs $female^{-1}$ were observed daily until adult death. The data for adult longevity, pre-oviposition, oviposition and post-oviposition periods were also recorded. The net reproductive rate of increase (R_0), cohort generation time (T_c), and the intrinsic rate of natural increase (r_m) were calculated as defined by Birch (1948). The intrinsic rate of natural increase was then estimated using the formula

$\Sigma e^{-rm*x} l_x * m_x = 1$ where x is age in days, l_x is proportion of females surviving to start of age interval x and m_x is an average number of female eggs laid by a female of age x. Finally, the finite rate of increase (λ) and population doubling time was calculated following the method of Tanigoshi et al. (1975).

Results

Biology of *S. pauperculus* and *S. siphonulus*

Development of *Stethorus* spp. composes of the egg, 4 larval stages, pupa and adult. Both sizes and duration of each developmental stage were presented in Tables 1 and 2. However, *S. indira* failed to complete its development when *T. urticae* was provided as prey. The preliminary experiment indicated that only 85% of *S. indira* eggs hatched into first instar larvae. Unfortunately, 12.5% of these larvae survived and molted into second instar larvae, finally, all of them died before molting into third instar larvae. Therefore, this species was discarded from all experiments.

S. siphonulus deposited eggs singly or in groups, scattering on the upper and lower leaf surfaces while *S. pauperculus* laid egg singly on the leaf surface, preferably on the underside. Eggs of both species are of the same size, elongate and bluntly rounded at both ends. The newly laid eggs of *S. siphonulus* were red in color, with reticulate pattern covering the egg shell while the egg shell of *S. pauperculus* had a smooth surface and pale yellow in color. Prior to hatching, *S. siphonulus* eggs gradually changed into orange-red color with 2 distinct black spots. On the other hand, *S. pauperculus* eggs gradually changed into yellow color with 2 red eye spots one day before hatching. The incubation period of *S. siphonulus* eggs was significantly shorter (2.31 days) than that of *S. siphonulus* (3.10 days).

The newly emerged larva of *S. pauperculus* had a round body in cross section, with transparent brownish yellow color where the body of *S. siphonulus* larva was relatively flat, with yellowish-brown in color. The color of both larvae gradually became darker as time progressed. *Stethorus* larvae

Table 1 Body width, body length and head capsule width (mm) of immature stages of *Stethorus pauperculus* and *S. siphonulus* fed with *Tetranychus urticae* at 27-28°C, 70-75% RH, 12:12 L:D regimes[1/].

Developmental stage	*Stethorus pauperculus* (n = 20)			*Stethorus siphonulus* (n = 20)		
	Body width	Body length	Head capsule width	Body width	Body length	Head capsule width
Egg	0.189±0.003	0.355±0.004		0.183±0.004	0.339±0.006	
1st instar larva	0.170±0.003	0.570±0.011	0.149±0.0006	0.209±0.005	0.550±0.014	0.150±0.000
2nd instar larva	0.256±0.006	1.053±0.022	0.175±0.0002	0.358±0.008	1.055±0.025	0.196±0.002
3rd instar larva	0.334±0.009	1.331±0.029	0.200±0.0002	0.482±0.019	1.436±0.034	0.232±0.002
4th instar larva	0.488±0.010	1.939±0.048	0.250±0.000	0.679±0.016	1.851±0.040	0.299±0.001
Pupa	0.767±0.068	1.145±0.012		0.995±0.011	1.419±0.014	

[1/] Data are shown as mean ± SE.

Table 2 Duration of immature stages of *Stethorus pauperculus* and *S. siphonulus* fed with *Tetranychus urticae* at 27-28°C, 70-75% RH, 12:12 L:D regimes[1/].

Developmental stage	Duration of immature stage (day)	
	S. pauperculus (n = 20)	*S. siphonulus* (n = 20)
Egg	3.10 ± 0.14 a	2.30 ± 0.11 b
1st instar larva	2.30 ± 0.11 a	2.10 ± 0.12 b
2nd instar larva	1.25 ± 0.10 a	1.00 ± 0.00 b
3rd instar larva	2.15 ± 0.15 a	1.05 ± 0.05 b
4th instar larva	2.15 ± 0.11 a	1.95 ± 0.11 a
Pupa	3.10 ± 0.10 a	2.85 ± 0.08 b
Total (egg-adult)	14.05 ± 0.22 a	11.25 ± 0.14 b

[1/] Data are shown as mean ± SE. Means in a row followed by the same letter were not significantly different at 0.05 level as determined by Lsd.

passed through 4 instars before entering the pupal stage. All larval instars of *S. siphonulus* were slightly bigger than those of *S. pauperculus* larvae (Table 1) and required significantly less time to develop in each instar. Hence, *S. siphonulus* completed its larval development within 6.11 days which was significantly faster than 7.85 days for *S. pauperculus* larvae. In addition, the longest period was observed in the first larval instar of both *Stethorus* spp. where 2.10 and 2.30 days were required for *S. pauperculus* and *S. siphonulus*, respectively which was equaled to 29% and 34% of its total larval development (Table 2).

Pupal stage of *S. siphonulus* and *S. pauperculus* was oval, flattened, subtruncate anteriorly and tapered posteriorly. At the early stage, pupa of *S. pauperculus* was creamy yellow in color, then drastically changed into black color. In contrast, *S. siphonulus* pupa was slightly bigger than *S. pauperculus* papa and the color was changed from grey to greyish black when it was near eclosion. The pupal stage of *S. siphonulus* lasted only 2.85 days while *S. pauperculus* papa spent more time (3.10 days) before molting into adult.

The newly emerged adult of both *S. siphonulus* and *S. pauperculus* was light brown in color and gradually changed to dark brown and black. Adult was convex and oval in shape. *S. siphonulus* completed its life cycle faster (11.25 days) than *S. pauperculus* (14.05 days).

Life Table of *S. pauperculus* and *S. siphonulus*

The biological parameters of *S. pauperculus* and *S. siphonulus* are presented in Table 3. *S. pauperculus* and *S. siphonulus* required 4.81 and 4.79 days before their first eggs were deposited. The egg laying period of *S. pauperculus* lasted 66.81 days where 3.82 eggs female^{-1} d^{-1} was recorded with the total egg production of 240.91 eggs female^{-1}. *S. siphonulus* laid eggs 27.72 days on average. This beetle deposited 5.38 eggs female^{-1} d^{-1} which were relatively higher than that of S. *pauperculus*, however, the fecundity rate (150.71 eggs female^{-1}) was considerably lower than that of *S. pauperculus*. The last egg was deposited approximately 2.56 and 2.73 days before the death of *S. pauperculus* and *S. siphonulus* females.

S. pauperculus male and female lived up to 100-110 days where only 61-66 days were recorded for *S. siphonulus* male and female. Male of both species had slightly shorter life span than the females. The longevity of *S. pauperculus* female and male averaged 74.19 and 67.78 days where only 35.24 and 31.30 days were noted for female and male of *S. siphonulus*, respectively (Table 3).

Adult survival and egg production declined as females aged (Figures 1 and 2). Two oviposition peaks of *S. pauperculus* were observed on day 16 and day 23 after adult eclosion (days 33 and 40 after egg hatched) and the survival rate started to decline on day 46 when adults were 33 days- old (Figure 1). The highest egg production of *S. siphonulus* was observed on day 20 when adult was 9 days-old and the number of egg decline abruptly thereafter (Figure 2). However, number of eggs increased again every 10-20 days which can be seen on day 30, 50, 61 and 75 when the adult was 20, 39, 50 and 64 days old.

The survival rate of *S. pauperculus* and *S. siphonulus* adults was 50.5 and 70.5% where the highest mortality rate was recorded in the first instar larva (21.95 and 10.99%) followed by egg (18 and 9%) and the second instar larva (12.5 and 7.4%). The life table data revealed that both *S. pauperculus* and *S. siphonulus* had a Type III survivorship curve where the number of individuals

Table 3 Oviposition rates and various durations (days) of *S. pauperculus* and *S. siphonulus* at 27-28°C, 70-75%RH, 12:12 L:D regimes[1/].

Parameter	*S. pauperculus* (n = 50)	*S. siphonulus* (n = 82)
Number of eggs female^{-1}	240.91 ± 8.04 a	150.71 ± 6.79 b
(Maximum fecundity)	(348)	(414)
Number of eggs female^{-1} d^{-1}	3.82 ± 0.12 a	5.38 ± 0.10 b
Pre-oviposition period	4.81 ± 0.19 a	4.79 ± 0.09 a
Oviposition period	66.81 ± 2.92 a	27.72 ± 0.99 b
Post-oviposition period	2.56 ± 0.19 a	2.73 ± 0.13 a
Female longevity	74.19 ± 2.86 a	35.24 ± 1.03 b
Male longevity	67.78 ± 3.46 a	31.30 ± 1.08 b

[1/] Data are shown as mean ± SE. Means in a row followed by the same letter were not significantly different at 0.05 level as determined by Lsd.

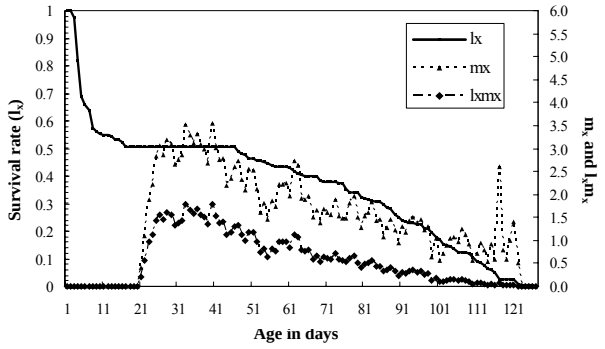

Figure 1 Age-specific survival rate (l_x), age-specific fecundity rate (m_x) and l_xm_x curves in *S. pauperculus*.

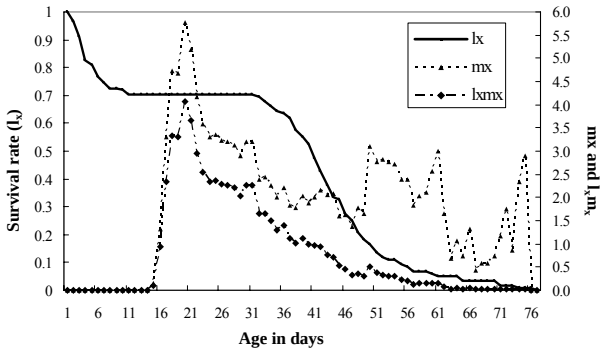

Figure 2 Age-specific survival rate (l_x), age-specific fecundity rate (m_x) and l_xm_x curves in *S. siphonulus*.

dropped drastically during the young stages (Figures 1 and 2). The biological attributes of *S. pauperculus* and *S. siphonulus* calculated from observed data included the followings: the mean generation time (T_c) = 51.588 and 29.125 days, the net reproductive rate (R_o)= 71.07 and 61.73 times, the intrinsic rate of natural increase (r_m)= 0.114 and 0.157 individual d^{-1}, the finite rate of increase (λ)=1.120 and 1.171 days and population doubling times (Dt) = 6.107 and 4.401 days.

Discussion

S. pauperculus completed its development slower than *S. siphonulus*. Chayopituk (1983) stated that *S. pauperculus* laid single eggs while Puttaswamy and ChannaBasavanna (1977) reported that eggs were laid singly or in groups of 2-5 eggs. Irshad (2001) stated that eggs of *S. pauperculus* were laid in clusters. In our study, we observed that all *S. pauperculus* eggs were laid singly but *S. siphonulus* eggs were laid both singly or in a group of 2-4 eggs. Raros and Haramoto (1974) reported that *S. siphonulus* deposited a single egg in a colony of spider mite which is contrast to our findings. They also observed that eggs of *S. siphonulus* were light orange in color and turned into grayish-black before hatching while we noticed that such eggs changed from red to orange-red color prior to hatching. Sarinkapaibul (1974) found that newly laid egg of *S. vagans* was red in color with reticulate pattern on the egg shell which is similar to our finding. Inamullah (2000) indicated that eggs of *S. vagans* was translucent white and turned to pale-yellow after 4-5 h. Each egg had 2 red eye spots which developed one day before hatching which was contrast to this result where only 2 black spots were observed in a *S. siphonulus* egg. Surprisingly, descriptions and figures of all *S. siphonulus* instars reported by Inamullah (2000) matched better with *S. pauperculus*. Hence, we decided not to include his data in our discussion on *S. siphonulus*.

Eggs of *S. pauperculus* reported by Puttaswamy and ChannaBasavanna (1977) were pale-pink to deep-pink in color which was contrast to this finding where only pale-yellow eggs were observed. The egg reported by Puttaswamy and ChannaBasavanna (1977) was also slightly larger

(0.20 mm wide, 0.38 mm long) than this result. However, eggs of *S. pauperculus* reported by Chayopituk (1983) showed similar color and approximately the same size as stated in this study.

In this experiment, 82 and 91% of *S. pauperculus* and *S. siphonulus* eggs hatched at 27-28°C, 70-75% RH, respectively. Puttaswamy and ChannaBasavanna (1977) indicated that 96% of *S. pauperculus* eggs hatched at 24-26°C, 74-81% RH which was considerably higher than this finding. Raros and Haramoto (1974) reported 84% survival rate of *S. siphonulus* eggs reared at 27-32°C, 50-60% RH and Sarinkapaibul (1974) recorded 92% viable egg of *S. vagans* at 95% RH. However, Mori et al. (2005) found that temperature did not alter the number of viable egg of *Stethorus japonicus* Kamiya.

Eggs of *S. pauperculus* hatched within 3.10 days which was quite shorter than 3.87 and 4.65 days at 28 and 24-26°C, respectively as reported by Chayopituk (1983) and Puttaswamy and Channa-Basavanna (1977). In addition, the incubation period of *S. pauperculus* eggs was in the same range as those of *S. punctillum* and *S. japonica* where 3.4 and 3.2 days were noted (Jiang et al., 1982; Mori et al., 2005). However, *S. pauperculus* eggs developed slower than *S. siphonulus* eggs where only 2.3 days were required at 27-28°C. Raros and Haramoto (1974) and Sarinkapaibul (1974) also reported that the incubation period of *S. vagans* lasted only 2.9 days at 27-32°C.

All larval instars of *S. pauperculus* are slightly larger than those reported by Chayopituk (1983) as can be determined by slightly larger head capsule width. In addition, Puttaswamy and Channa-Basavanna (1977) revealed that all instars of *S. pauperculus* larvae fed on *T. cucurbitae* had slightly wider bodies but shorter in length comparing to those larvae fed with *T. hydrangeae* (Chayopituk, 1983) and *T. urticae* in this study.

Puttaswamy and ChannaBasavanna (1977) reported that newly hatched *S. pauperculus* larva was dark-brown which was contrasted to this experiment where it was transparently yellow or pale in color. Irshad (2001) stated that color of *Stethorus* larvae varied from light-black to brown. The total time required for larval development of *S. pauperculus* in this study coincided with those reported by Puttaswamy and ChannaBasavanna (1977) and Chayopituk (1983). In contrast, they found that the forth instar larvae of *S. pauperculus* required more times, 2.85 and 2.4 days, as compared to those of the first instar larvae, 1.53 and 1.90 days, after being fed with *T. cucurbitae* and *T. hydrangeae*, respectively where our result clearly indicated that the first instar larva spent the longest time to complete its development.

Raros and Haramoto (1974) revealed that the full grown *S. siphonulus* larva was yellowish-brown which is similar to this result. However, they found that larva spent most time to develop in the forth larval stage (2.6 days) as compared to 2 days for the first instar larva. Our results revealed that the first larval instar required the longest time (2.1 days) to develop compared to all other larval instar. This result is also in agreement with that of Sarinkapaibul (1974) where up to 1.9 days was required by the first instar larva to complete its development and only 1-1.3 days were needed for the completion of development of other larval instar. The sizes of all larval instar of *S. siphonulus* in this study were quite similar to the reported by Raros and Haramoto (1974) and Sarinkapaibul (1974).

Pupal appearance of *S. pauperculus* was quite similar to those reported by Puttaswamy and ChannaBasavanna (1977) and Chayopituk (1983). However, pupae of *S. pauperculus* fed with *T. cucurbitae* and *T. hydrangeae* were slightly larger and needed 3.93 and 4 days to complete the development which was considerably longer than 3.10 days in this finding at similar condition. In addition, the size of adult in this study, 0.73 x 1.08 mm, was slightly greater than 0.68 x1.05 mm of Chayopituk (1983) but rather smaller than 1.0 x1.47 mm as mentioned by Puttaswamy and Channa-Basavanna (1977). *S. siphonulus* pupa completed its development in 2.85 days which was slightly faster than 3 days as reported by Raros and Haramoto (1974) and Sarinkapaibul (1974). The size of *S. siphonulus* adult, 1.04×1.43 mm, was slightly greater than those of *S. pauperculus*. Moreover, it is quite larger than 0.95×1.39 and 0.95×1.50 mm as reported by Sarinkapaibul (1974) and Raros and Haramoto (1974), respectively.

S. pauperculus fed on *T. urticae* completed its development within 14.05 days which was relatively shorter than 15.07 and 16.21 days of those fed with *T. hydrangeae* and *T. cucurbitae*,

respectively as reported by Chayopituk (1983) and Puttaswamy and ChannaBasavanna (1977). It was probably due to the quality of prey species. Kishimoto (2003) stated that development of *S. japonicus* differed greatly with prey species which was probably due to a physiological nature such as nutrients of each prey species. In contrast, *S. siphonulus* fed on *T. urticae* required only 11.25 days to complete its development which was significantly faster than *S. pauperculus*. This result was in the same range as 12.7 days of *S. punctillum* fed on *Tetranychus mcdaieli* McGregor at 28°C (Roy et al., 2002) and 12.0-12.4 day of S. *japonicus* fed *T. urticae* at 27.5 °C Mori et al. (2005).

We observed that the larvae of *S. pauperculus* and *S. siphonulus* preferred eggs while adults fed mostly on nymphal and adult *T. urticae*. Puttaswamy and ChannaBasavanna (1977) mentioned that adult *S. pauperculus* fed on all stages of spider mite, preferably ovipositing females which was contrast to this finding. Chayopituk (1983) reported that prey of different stages did not alter the rate of development of *S. pauperculus* fed with *T. hydrangeae* even though *Stethorus* larvae fed with only eggs tended to require longer time to complete its development as compared to those fed with mixed stages of spider mite. Moreover, larvae that fed on either eggs alone or mixed stages of spider mites, did not differ in body size and head capsule width.

Both larval and adult stages of *S. pauperculus* and *S. siphonulus* found their prey by direct contact which was in agreement with Fleschner (1950) and Houston (1983) who believed that *Stethorus* found their prey by contact. However, Hull et al. (1977) found that *Stethorus punctum* (LeConte) might use some other stimulus other than random searching to find their prey while Sabelis and van de Bann (1983) demonstrated that *Stethorus* might detect their prey by chemicals such as kairomones as well.

Mating of *S. pauperculus* and *S. siphonulus* occurred many times during the female life span which is similar to *S. punctillum, S. gilvifrons,* and *S. nigripes* (Helle and Sabelis, 1985b; Richardson, 1977). Sex ratio of *S. pauperculus* and *S. siphonulus* was 1: 1.40 or 58% female which was similar to many *Stethorus* spp. such as *Stethorus loi* Sasaji, *S. nigripes, S. tridens* and *S. picipes* (Tanigoshi and McMurtry, 1977; Richardson, 1977; Fiaboe et al., 2007). Mori et al. (2005) also found that sex ratio of *S. japonicus* ranged from 53.9 -57% female at 20, 25 and 30°C which was similar to this finding.

The pre-oviposition period of *S. pauperculus* and *S. siphonulus* in this study was slightly longer than 3.3 days of *S. japonicus* at 30°C (Mori et al., 2005) and also slightly shorter than 5.3 and 5.6 days of *S. punctillum* at 28°C and *Stethorus picipes* (Casey) at 24.5°C, respectively (Tanigoshi and McMurtry, 1977; Roy et al., 2003). In contrast, Fiaboe et al. (2007) reported that the pre-oviposition period of *S. tridens* reared at 27°C was 10.3 days which was 2.5 times longer than this finding. Moreover, Raros and Haramoto (1974) found that *S. siphonulus* female laid the first egg 1.8 days after initial mating which differed from our results. The oviposition period of *S. siphonulus* (27 days) was quite similar to 3 weeks of S. *siphonulus* as reported by Raros and Haramoto (1974), but differed greatly from 48.9 days of *S. vagans* as reported by Sarinkapaibul (1974). In addition, similar results were also reported on *S. punctillum* (21.1 days) and *S. tridens* (31.2 days) (Roy et al., 2003; Fiaboe et al., 2007). In contrast, oviposition period of *S. pauperculus* (66.81 days) was approximately 2-3 times longer than those of *S. punctillum* and *S. tridens*, and slightly longer than 51.6 days of *S. japonicus* (Roy et al., 2003; Mori et al., 2005; Fiaboe et al., 2007). The post-oviposition period of *S. pauperculus* (2.56 days) and *S. siphonulus* (2.73 days) was 4.5 and 4.2 times shorter than reported for *S. japonicus* (11.6 days) and 11.7 and 11.06 times shorter than *S. tridens* (30.2 days) (Mori et al., 2005; Fiaboe et al., 2007). However, Raros and Haramoto (1974) revealed that *S. siphonulus* stopped producing egg 9 days before the female died which was 3.2 times longer than our result.

Fiaboe et al. (2007) observed that female *S. tridens* had an oviposition peak for 17 days after eclosion which coincided with 16 days of *S. pauperculus.* In contrast, female *S. siphonulus* reached its peak of oviposition within 9 days after adult emergence which was considerably shorter than 3 weeks reported by Raros and Haramoto (1974). However, Mori et al. (2005) revealed that daily egg production of *S. japonicus* reached a peak on day 33 at 25°C and day 26 at 30°C, and female

started to die on day 55, 39 and 22 at 20 °C, 25 °C and 30°C which differed from our results for *S. pauperculus* and *S. siphonulus.*

Both female longevity and fecundity rate of *S. pauperculus* varied greatly where female lived 33-110 days, total egg deposition ranging from 133-348, with daily fecundity of 1-20 eggs per female. This result agreed with Fiaboe et al. (2007) where the age of *S. tridens* female fed with *Tetranychus evansi* Baker and Pritchard ranged from 23-112 days. Each *S. tridens* female laid 1 to 21 eggs per day where the total of 8-383 eggs were recorded per female. The overall daily fecundity and female longevity of *S. pauperculus* and *S. tridens* was quite similar, however, total fecundity of *S. pauperculus* (240 eggs female^{-1}) was twice as much of those recorded for *S. tridens* (123 eggs female^{-1}). The reason was that *S. pauperculus* has a longer oviposition period as compared to *S. tridens* where 67.15 and 31.2 days were noted, respectively. Moreover, the pre-oviposition period of *S. tridens* lasted 30.2 days which was extremely longer than 2.56 days of *S. pauperculus*.

Females of *S. siphonulus* in this study lived 35.24 days (21-66 days), deposited 150.71 eggs (49-414 eggs) with daily production of 5.38 days (2-7 eggs). This finding was similar to Raros and Haramoto (1974) where *S. siphonulus* female lived 32.4 days, laid an average of 170 eggs female^{-1} and produced a maximum of 7 eggs female^{-1} d^{-1}. In contrast, Sarinkapaibul (1974) reported that *S. vagans* females fed on *T. cinnabarinus* at 30°C lived longer (53.2, range 33-70 days) and produced more eggs (401.9, range 114-925 eggs female^{-1}) than our finding. The reason for the difference is that each female laid a greater number of eggs (7.53 eggs d^{-1}) and the oviposition period was also 2 times longer than our results.

Life table study indicated the highest mortality of *S. pauperculus* and *S. siphonulus* occurred in the first larval instar. This finding agreed with Mori et al. (2005) who stated that survival rate of *S. japonicus* decreased at the first instar. However, they concluded that adult survival rate of *S. japonicus* fed with *T. urticae* was 71.2-91.5% at 17.5-30°C which was higher than 50.5% of *S. pauperculus* in our results. Chayopituk (1983) found that *S. pauperculus* fed *T. hydrangeae* exhibited 92.16% egg hatchability and 73.04% adult survival rate which were relatively higher than 82 and 50.5% in our findings. This was probably due to prey quality as Kishimoto (2003) mentioned that both development and oviposition rate of *S. japonicus* differed greatly with prey species. Up to 70.5% of *S. siphonulus* adults survived at 27°C which was similar to 71.2% of *S. japonica* fed with *T. urticae* (Mori et al., 2005).

The biological parameters of *S. pauperculus* revealed that T_c= 51.588 days, R_o= 71.07 times, r_m= 0.114 individual d^{-1}, λ =1.120 and Dt= 6.107 days. This result agreed with Fiaboe et al. (2007) who revealed that at 27°C, *S. tridens* had R_o, r_m and λ equaled 53.231, 1.104 and 1.11, therefore the population would be doubled within 6.6 days. However, their results indicated that T_c of *S. tridens* was only 38.2 days which was shorter than 51.588 days for *S. pauperculus* in our findings. On the other hand, our results showed that T_c of *S. siphonulus* was only 29.12 days where R_o= 61.73 times, r_m= 0.154 individual d^{-1}, λ =1.171 and Dt= 4.401 days. Mori et al. (2005) reported that *S. japonicus* fed with *T. uricae* at 25°C had considerably higher values of T_c and R_o (51.103 days and 270.494 times). In contrast, the r_m (0.158 individual d^{-1}), λ (1.169) and Dt (4.431 days) values of *S. japonicus* is in agreement with those values of *S. siphonulus*.

Bonato (1999) stated that estimates of r_m were difficult to compare between studies due to many factors such as genetic variation, rearing methods, environmental conditions including sex ratio and the rate of survival to the adult stage often assumed, instead of being actually measured. The r_m value is strongly correlated with developmental time and oviposition rate (Sabelis, 1985a; Wrensch, 1985; Dixon, 2000). Sabelis (1985b) mentioned that the r_m value of acarophagous lady beetles was quite lower (0.100-0.156 individual d^{-1}) than its prey (0.160-0.293 individual d^{-1}) at 25°C. The data in this study also indicated that the r_m value of *S. pauperculus* and *S. siphonulus* fell in the same range (0.114 and 0.158 individual d^{-1}), hence, both *S. pauperculus* and *S. siphonulus* may not provide consistent control over *T. urticae* by their reproductive numerical response to the mite alone.

Conclusions

S. pauperculus and *S. siphonulus* are able to feed on *T. urticae* which is one of the most serious acarine pests in agriculture. *S. pauperculus* requires more time to complete its development than *S. siphonulus*. However, both female and male *S. pauperculus* live longer and produce more offspring than *S. siphonulus*. More information especially the effect of environment such as temperature, humidity and prey density on predator development is needed to be investigated before the biological control program using *S. pauperculus* or *S. siphonulus* as the biological agent can be developed.

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