POTENTIAL OF ANTHOCORID BUG, *WOLLASTONIELLA ROTUNDA* YASUNAGA & MIYAMOTO (HEMIPTERA: ANTHOCORIDAE) FOR BIOLOGICAL CONTROL OF *THRIPS PALMI* KARNY (THYSANOPTERA: THRIPIDAE)

INTRODUCTION

Thrips palmi Karny (Thysanoptera: Thripidae) is an important insect pest of economic crop in many country. It originated in Southern Asia and spread from there during the 20th century and became to the key pest throughout Asia, Africa, Oceania, America and the Caribbean.

T. palmi is a polyphagous pest. It damage a wide range of ornamental and vegetable crop, especially plants in the families Cucurbitaceae and Solanaceae, such as cucumber, eggplant, chilli, melon, onion, pepper, potato and watermelon. Larvae and adults of *T. palmi* feed gregariously on leaves, stems, flowers and fruits. It has the potential to introduced and spread several non-indigenous viruses (Tospoviruses). It is difficult to control by insecticide in the field. There is strong indication that *T. palmi* abundance and damage are increased by application of some insecticide. The growers have to increase application of chemical insecticide to control *T. palmi* population. Through an excessive uses of insecticide, its residue in soil and water, change of biological pattern of pests and preys become more important. The use of natural enemies should be considered as and alternative way to control *T. palmi*.

Biological control is consider as the best methology for control *T. palmi* in the field. Many parasite and predator of *T. palmi* were found and report from many investigation. Anthocorid bug, *Wollastoniella rotunda* Yasunaga and Miyamoto (Hemiptera: Anthocoridae) was an important predator for *T. palmi*. It was found and reported as *Bilia* sp. by Horose *et al*., (1993). Yasunaga and Miyamoto (1993) was redescribed and reported that *Bilia* sp. collected from Thailand was a new species belonging to the genus *Wollastoniella* and it was described as *Wollastoniella rotunda*. Several year later, Yasunaga (1995) described another species of

Wollastoniella, as *Wollastoniella parvicuneis*, also from Thailand, both of them collection on eggplant.

The objective of this study was investigated on the suitable preys for mass rearing of *W. rotunda* including the efficiency of *W. rotunda*. The results from this study will be utilized for biological control of *T. p*almi in Thailand.

LITERATURE REVIEW

Anthocorid bugs were usually found on flowers but some species occur under loose bark, in leaf litter and in decaying fungi. There are between 500 to 600 species distributed over the world. These bugs are small (2 - 5 mm in length), elongate-oval and somewhat flattened, and many species are black with whitish marking (Borror *et al*., 1989; Schaefer and Panizzi, 2000). All anthocorids are predatory both nymphs and adults (Hill *et al.*, 1982). This predatory anthocorid feed on mites, aphids, psyllids, scales, wooly aphids, thrips and egg of some Lepidoptera (Roy and Bellows, 1996).

Wollastoniella rotunda was a small insect in family Anthocoridae. It was described as new species by Yasunaga and Miyamoto in 1993 (Yasunaga and Miyamoto, 1993). Taxonomic position of *W. rotunda* was:

Class Insecta
- Subclass Pterygota
  - Infraclass Neoptera
    - Division Exopterygota
      - Superorder Hemipteroidea
        - Order Hemiptera
          - Suborder Heteroptera
            - Superfamily Cimicoidea
              - Family Anthocoridae
                - Subfamily Anthocorinae

W. rotunda was generally blackish body, small and rounded; dorsal surface densely clothed with silvery pubescence. Head was blackish, shining and much wider than long in dorsal. Antennae was yellow; segment I dark-ended and very short; segments II gradually thick-ended toward; segment III shorter than II; segment IV reddish brown. Thorax was generally blackish;

scutellum sub shining, densely covered with silvery pubescence; hemelytra blackish, sub shining and somewhat shagreened. Legs were yellowish brown, short; femura and apices of tarsi darkened. Abdomen was entirely shiny blackish (Yasunaga and Miyamoto, 1993).

Rattanaka (2003) reported that the eggs were inserted singly in the upper or lower of eggplant leaves in the midrib or major veins. Eggs are jug-shaped and round-oval. The newly laid eggs were creamy white and became red before hatching. The newly hatched nymph was predacious. It attacked prey by using stylet piercing into the prey. Stylet length was long when compared with body length. It had five nymphal instars. The adult was rounded, body surface shinning, punctuate, uniformly, covered with silky hair, chestnut brown in color. Antennae were yellowish brown all four segments in female, fourth segment tinged with reddish in male. Hemelytra covered with silky hair and chestnut brown in color. The female was slightly larger than the male in size and could be differentiated by the abdomen, male abdominal distinctly twisted in general shape.

The incubation period was 6.60 $\pm$ 0.50 days, ranging from 6 to 7 days. The nymphal development from the first to the fifth instar were 2.20 $\pm$ 0.41 days, ranging from 2 to 3 days; 2.26 $\pm$ 0.45 days, ranging from 2 to 3 days; 2.00 $\pm$ 0.69 days, raging from 1 to 4 days; 2.94 $\pm$ 0.43 days, ranging from 2 to 4 days; 4.76 $\pm$ 0.75 days, ranging from 4 to 6 days, respectively. The total period of nymphal stage was 14.20 $\pm$ 1.22 days, ranging from 12 to 17 days. The longevity of male and female adults were 9.43 $\pm$ 3.99 days, ranging from 4 to 14 days and 13.60 $\pm$ 7.47 days, ranging from 5 to 28 days, respectively. The total life cycle of male and female were 29.71 $\pm$ 3.59 days, ranging from 24 to 34 days and 34.60 $\pm$ 6.69 days, ranging from 26 to 47 days, respectively.

Rattanaka *et al*., (2001) study on the population of *W. rotunda* under the field condition at Heumonthong and Tungbua, Kamphaeng Saen, Nakhon Pathom during November 1998 to October 2000 and reported that the highest peek of *W. rotunda* was occurred in December 1998 and October 2000 and the lowest in August, October and November 1999.

Shima and Hirose (2002) investigated on possibility using *W. rotunda* as a biological control agent against *T. palmi* in greenhouses, the effect of temperature on the development and survival of *W. rotunda* was investigated. The developmental period and survival of *W. rotunda* eggs and nymphs when reared on *T. palmi* were measured at eight constant temperatures: 15, 17.5, 20, 22.5, 25, 27.5, 30 and 32 ^{o}C. At these temperatures, the developmental times of *W. rotunda* eggs and nymphs ranged from 6.6 to 29.9 days and 14.0 to 47.6 days, respectively. More than 70% of the eggs hatched at temperatures from 17.5 to 30.0 ^{o}C. Nymphal survival rates reached 70% or more for all the temperatures tested. These results suggested that *W. rotunda* could survive and develop in Japanese greenhouses during winter season. Nakashima *et al*., (2004) reported that *W. rotunda* had the potential to be an effective control agent for *T. palmi* on the eggplant, even during the winter in temperate regions. It was successfully developed, reproduced and suppressed *T. palmi* populations in the cage trials under the conditions found in the winter greenhouses.

Urano *et al*., (2003) reported that when releasing of *W. rotunda* for controlled *T. palmi* at the ratio 1 : 4 (adult bug : thrips) every month. It was successful in controlling *T. palmi* population in the greenhouse when the population of thrips was low density (0.06 adults per leaf). These results confirmed that *W. rotunda* was effective as a biological control agent against *T. palmi* in winter greenhouse.

Maneerat *et al*., (2005) study on prey-preference of *W. rotunda* and reported that on non-choice test; early nymphs consumed *T. palmi, Aphis gossypii* Glover and *Tetranychus* sp.; last nymphs consumed *T. palmi, A. gossypii*, egg of *Corcyra cephalonica* (Stainton) and *Tetranychus* sp.; adults consumed *T. palmi, Amrasca biguttula biguttula* Ishida, *Pseudococcus* sp., egg of *C. cephalonica* and *Tetranychus* sp., and choice test revealed that; early nymphs preferred only *Tetranychus* sp., last nymphs preferred only *T. palmi* and adults preferred *T. palmi* and egg of *C. cephalonica*.

Thrips palmi **Karny**

Thrips are serious insect pests of several crops throughout the world, causing damage through direct damage feeding as well as being vectors of destructive plant viruses (Ananthakrishman, 1993). *Thrips palmi* Karny was first described in 1925 from tobacco plants in Sumatra and Java (Karny, 1925). Its infested many host plants including vegetable, ornamental and agronomic. It had many common names, there were palm thrips, southern thrips and melon thrips. Taxonomic position of *T. palmi* was;

Class Insecta
Subclass Pterygota
Infraclass Neoptera
Division Exopterygota
Superorder Hemipteroidea
Order Thysanoptera
Suborder Terebrantia
Family Thripidae
Subfamily Thripinae

Synonyms: *Thrips leucadophilus* Priesner, *Thrips gossypicola* (Priesner) Ramakrishna & Margabandhu, *Chloethrips aureus* Ananthakrishnan & Jagadish and *Thrips gracilis* Ananthakrishnan & Jagadish (OEPP/EPPO, 1989).

Yoshihara (1982), Hirose (1991) and Lewis (1997) reported that *T. palmi* became important pest of many vegetable agronomic and ornamental crops in Southeast Asia. During the 20^{th} country, *T. palmi* was present throughout Asia and widespread in Central America and Caribbean. In 1978, it has widely distributed to Sudan, Indonesia and Taiwan before suddenly becoming a pest in Japan; since then it had spread throughout the tropics and sub-tropic regions (Mound, 1997). Sakimura *et al*., (1986) reported that since it has been recorded, mainly in Asia on a variety of plants especially solanaceous crops (excepting tomato), curcubits, legumes and ornamental plant and more recently in Florida in 1990 (South, 1991). Medina (1980) reported that, *T. palmi* was outbreak and destroyed 80% of watermelon plantations in Central Luzon and Laguna. Recently, Wangboonkong (1981) reported that *T. palmi* became a serious pest of cotton in Central areas of Thailand in 1997 to 1998. More recently, Cardona *et al*., (2002) reported that *T. palmi* was became a serious pest of legumes, solanaceous crops and cucurbits in Columbia 1997.

The addition, report from Sakimura *et al*., (1986) reported that it outbreak in Japan and Caledonia and Frantz *et al*., (1995) reported that it was damaged on both of autumn and spring vegetable crops in Southern Florida. In recently, Vierbergen (2001) reported that it was found from imported consignments at points of entry in Europe and U.S.A. It was commonly occurred in products for final consumption, but was rarely found in plants for planting. Most detections related to ornamentals and especially orchid cut flowers imported from Thailand. Morris and Waterhouse (2001) reported that in Myanmar, *T. palmi* was discovered as an important pest in solanaceous and cucurbits crops.

Life stages of *T. palmi* were the egg, two larval instars, two pupal instars and the adult. Egg was one deposited in leaf tissue. It was slightly, pale white in color and bean shaped in form. *T. palmi* have two instars. Larvae were pale, transparent yellow in color and similar to the adults in body form but lack wing buds. At the completion of the larval instars the insect usually descends to the soil where it constructs a small earthen chamber for a pupation site. Pupal stage had two instars. Both instars were non-feeding stages. Prepupal instar was nearly inactived and pupal instar was inactive. The prepupae and pupae resemble the adults and larvae in form, except that they possess wing pads. The wing pads of the pupae were longer than that of the prepupae. If their containing cell breaks, these stages are able to walk slowly and clumsily. Adults were pale yellow or whitish in color, but with numerous dark setae on the body. A black line was resulting from the juncture of the wings, run along the back of the body. The hairs or fringe on the anterior edge of the wing were considerably shorter that those on the posterior edge.
The duration of the egg, larva, pupa, male and female adults were 7.5, 5, 4, 7 - 20 and 10 - 30 days, respectively under 26 ^{o}C condition (Giling, 1992) and female and daily oviposition rate

reached maximums, the values for the last 2 parameters being 59.6 eggs/female and 3.8 eggs/day, respectively under 25 ^{o}C (Kawai, 1985).

T. palmi, a polyphagous feeder on many hosts, included over 50 plant species representing are 20 taxonomic families (Wang and Chu, 1986). It was quickly built up heavy infestations causing severe injury. Both larvae and adults were fed gregariously on leaves, stems, flowers and fruits and burst the cell of its host plants and sucking up the exposed cell sap (Kirk, 1997). It was frequently found in pockets, cracks, or crevices on host material. Heavily infested plants were characterized by silvered of bronzed appearance of leaves, stunted leaves and terminals, and scarred and deformed fruits (Lewis, 1973). Besides causing damage from feeding of *T. palmi* has also been reported to transmit an isolate of tomato spotted wilt tospovirus (TSWV) that infects watermelon in Taiwan (Yeh *et al*., 1992) and in Japan (Iwaki *et al*., 1984). Moreover, *T. palmi* were transmitted peanut bud necrosis tospovirus (PBNV) and watermelon silver mottle tospovirus (WSMV) (Pappu, 1997).

Lewis (1973) reported that cultural practices, irrigation or flooding could be used to destroy thrips which spend pupal stage in the soil. Culliney (1990) found that blue and white traps were attractive colors had been used for *T. palmi*. The addition, heavy rainfall in thought to decrease *T. palmi* number (Etienne *et al.*, 1990). Chemical insecticides were remained one of the method to prevent this problem. Sastrosiswojo (1991) recommended insecticides that could applied with *T. palmi* were quianlphos, endosulfan, mercaptodimethur, acephate, formetanate, hydrochloride and cypermethrin. A survey of agrochemical used by farmers in the lowland vegetable-growing areas in Indonesia revealed that farmers must applied at least 16 sprays (at 3 - 4 days intervals) for controlling *T. palmi*. In Thailand, Bansiddhi and Poonchaisri (1991) recommended application of carbosulfan and prothiophes in orchid. However, *T. palmi* was resistanted to most kind of insecticides and it made *T. palmi* more serious damaged.

An attemp to control *T. palmi* by using the natural enemies was done by Hirose *et al.* (1993) in Thailand. He reported that eight species of natural enemies of *T. palmi* were found and reported that, *Megaphragma* sp. (Hymenoptera: Trichogrammatidae) was first recorded on eggplant in Chiang Mai; *Ceranisus menes* (Walker) (Hymenoptera: Eulophidae) is larval parasitoid reared from *T. palmi*; *Bilia* sp.(Hemiptera: Anthocoridae), both adults and nymphs attacked *T. palmi* larvae; *Orius* sp. (Hemiptera: Anthocoridae), adults were collected from eggplant in Chiang Mai; *Campylomma* sp. (Hemiptera: Miridae), adults were collected from eggplant in Nakhon Pathom; *Franklinothrips vespiformis* (Crowford) (Thysanoptera: Aeolothripidae), adults and larvae of this predacious thrips were found in the test plot at Bangkhen, Bangkok; *Amblyseius* sp. (Acarina: Phytoseiidae), predacious mite preyed on second instar larvae of *T. palmi* and *Phytoseius* sp. (Acarina: Phytoseiidae), this predacious mite was collected from the eggplants in Nakhon Pathom (Hirose, 1989 and Hirose *et al*., 1993).

MATERIALS AND METHODS

<u>Stock Culture of *Wollastoniella rotunda* Yasunaga and Miyamoto</u>

W. rotunda were collected from the eggplant field and kept in the plastic box (7.5 cm in high and 23 cm in diameter), with tightly fitting lids having a 10 cm diameters circular hole with wire-mesh screen for ventilation and provided *Tetranychus* sp. as food until adult emerged. The emerged adults were moved to rear on the eggplant which plant in plastic pots with *T. palmi* and *Tetranychus* sp. from stock culture for food in the insectary as shown in Figure 1.

<u>Stock Culture of Preys</u>

Stock Culture of *Thrips plami* Karny and *Tetranychus* sp.

The original stock culture of thrips (*T. palmi*) and spider mite (*Tetranychus* sp.) were obtained by field collecting and reared on eggplants which, were planted in the plastic pots**,** in the insectary. Adequate maintain content was provided for eggplant. By these methods it was possible to maintain stock culture of *T. palmi* and *Tetranychus* sp. as preys of *W. rotunda* for other experimental purposes (Figure 2 and 3).

Stock Culture of *Corcyra cephalonica* (Stainton)

C. cephalonica was reared in plastic boxes, measuring 22 x 33 x 9.5 cm, using the bran as food for larvae and waiting for adult emerged. It took about 45 days. The emerged adults of *C. cephalonica* were transferred to the fine net for oviposition. The egg was kept and then kept it in the freezer for utilized. By these methods it was possible to maintain stock culture of egg of *C. cephalonica* as preys of *W. rotunda* for other experimental purposes (Figure 4).

Figure 1 Stock culture of *Wollastoniella rotunda* Yasunaga and Miyamoto on eggplants in the insectary. (A) *W. rotunda* feeding on *Tetranychus* sp.

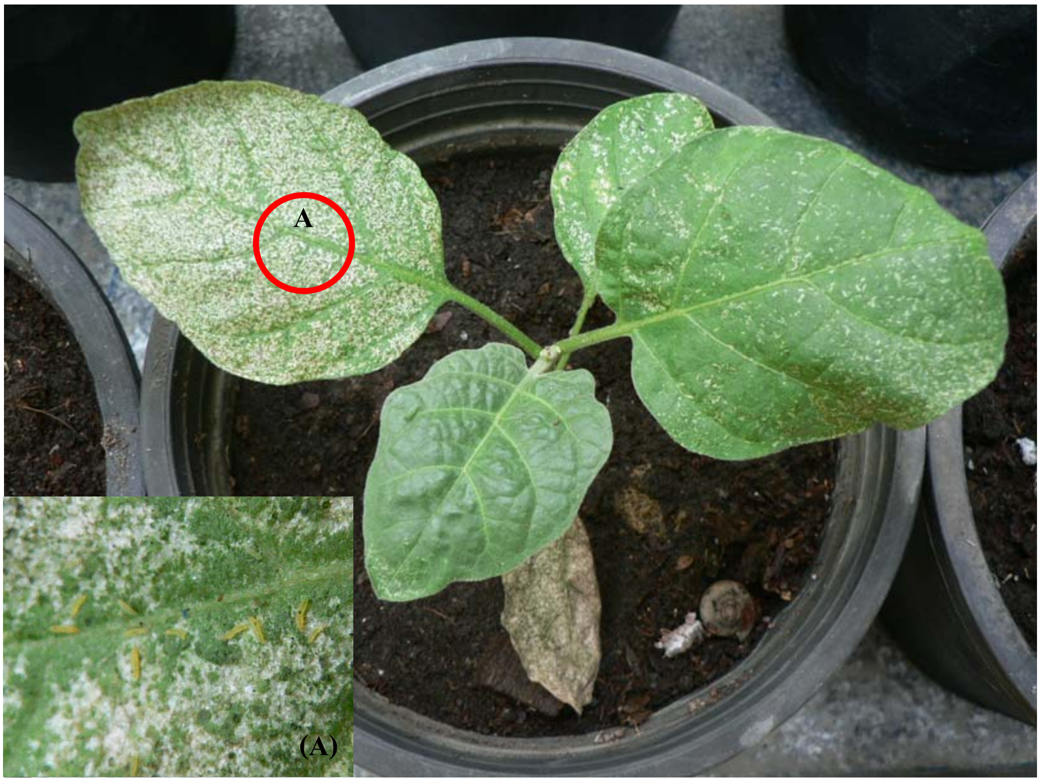


Figure 2 Stock culture of *Thrips palmi* Karny on eggplants in the insectary. (A) Larvae of *T. palmi*.

Figure 3 Stock culture of *Tetranychus* sp. on eggplants in the insectary. (A) Nymphs and adults of *Tetranychus* sp.

Figure 4 Stock culture of *Corcyra cephalonica* (Stainton). (A) Eggs of *C. cephalonica*.

Stock Culture of *Maconellicoccus hirsutus* (Green)

The original stock culture of pink mealybug (*M. hirsutus*) was obtained by field collecting and reared on the pumpkin and kept it in the dark room. By these methods it will be possible to maintain stock culture of *M. hirsutus* as preys of *W. rotunda* for other experimental purposes (Figure 5).

Biological Studies of *Wollastoniella rotunda* Yasunaga and Miyamoto

The leaf of eggplant with 20 newly laid eggs of *W. rotunda* was sealed the petiole by soaked cotton and put it into the vial. Eggs counting were made under the microscope. Then kept in the plastic boxes, measuring 14.5 x 21.5 x 7.5 cm until nymphs emerged. The newly hatched nymphs were transferred to new plastic petri dishes, measuring 5 cm in diameter which eggplant leaves, measuring 3 x 3 cm and soaked filter paper supplied for moisture. Larvae of *T. palmi* were provided daily as prey and changed fresh eggplant leaves every twice days. Daily observation was made and life history data recorded throughout the developmental period.

A new pair of newly emerged adult of *W. rotunda*, were kept in plastic petri dishes, measuring 5 cm in diameter with eggplant leaves, measuring 3 x 3 cm and soaked filter paper supplied for moisture. Each plastic petri dish were provided larvae of *T. palmi* daily as prey and changed fresh eggplant leaves every twice days. Body measurements of each stage were measured by micrometer under compound microscope. Daily observation was made on the number of eggs laid and life span of adults and other biological data were also recorded. Then analyzed, body measuring and developmental period in each stages of *W. rotunda* when fed with different preys. (Data were analyzed by using the Duncan's Multiple Range Test (DMRT) with SPSS for Windows version 11.)

The same technique was made by using *C. cephalonica* eggs, and *Tetranychus* sp. adults as prey for study biology of *W. rotunda*.

Figure 5 Rearing of *Maconellicoccus hirsutus* (Green) on pumpkin and (A) adults and crawlers of *M. hirsutus*.

<u>Biological Life Table of *Wollastoniella rotunda* Yasunaga and Miyamoto</u>

Biological life table of *W. rotunda* were constructed by using *T. palmi* larvae*, M. hirsutus* crawlers, *C. cephalonica* eggs and *Tetranychus* sp. adults as preys. They were carried out by using 300 newly laid eggs of *W. rotunda* for each respective kind of preys.

In each set of the study, leaves of eggplant with eggs of *W. rotunda* were cut from the stock culture and sealed the petiole by soaked cotton and put it into the vial (Figure 6). Eggs counting were made under the microscope and keeping in the plastic boxes, measuring 14.5 x 21.5 x 7.5 cm until nymphs emerged. The newly hatched nymphs were transferred to plastic petri dishes, measuring 5 cm in diameter which eggplant leaves, with soaked filter paper supplied for moisture. *W. rotunda* nymph in each petri dish were provided prey daily and changed fresh eggplant leaf every twice days. The number of individual nymphs of each kind of preys were recorded daily until adult emerged. The emerged adults were reared on eggplant leaves confine with fine net as shown in Figure 7. Data on the number of adults survived and number of eggs laid were recorded every day until the adults died. The recorded data were used for the construction and analysis of the biological life table, the net reproductive rate of increase (R_o), the capacity for increase (r_c), the finite rate of increase (λ) and the cohort gereration time (T_c) were calculated using techniques given by Laughlin (1965), Napompeth (1973) and Price (1984).

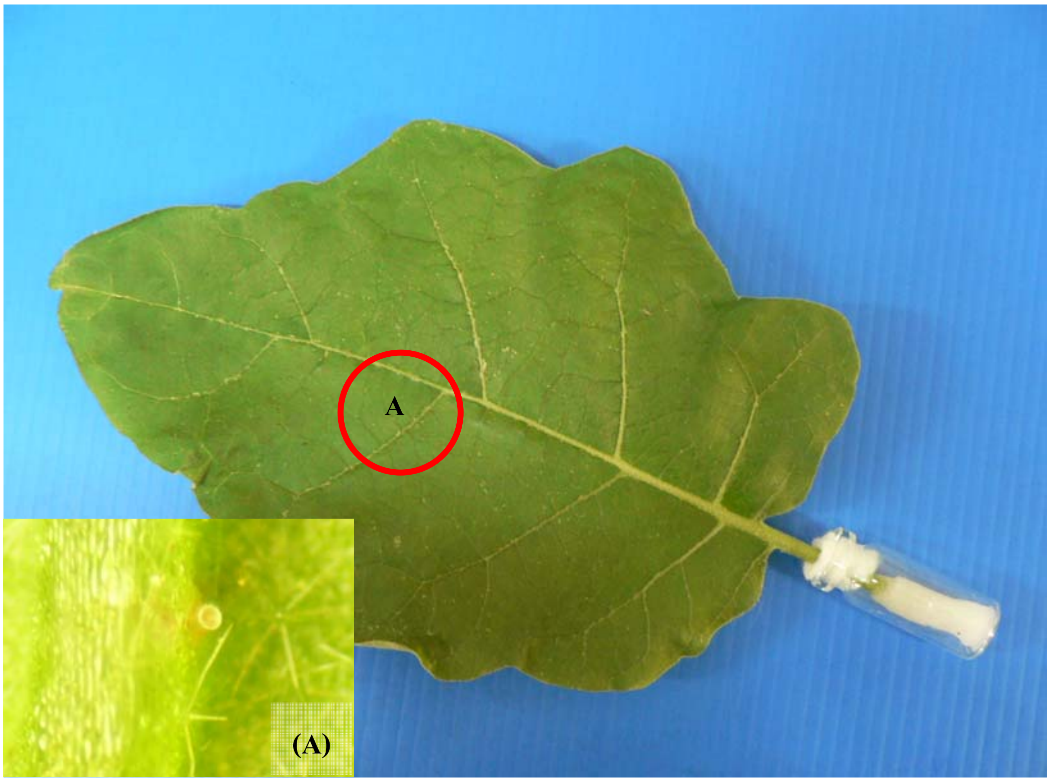


Figure 6 Methology for rearing *Wollastoniella rotunda* Yasunaga and Miyamoto on leaf of eggplant. (A) Egg of *W. rotunda*.

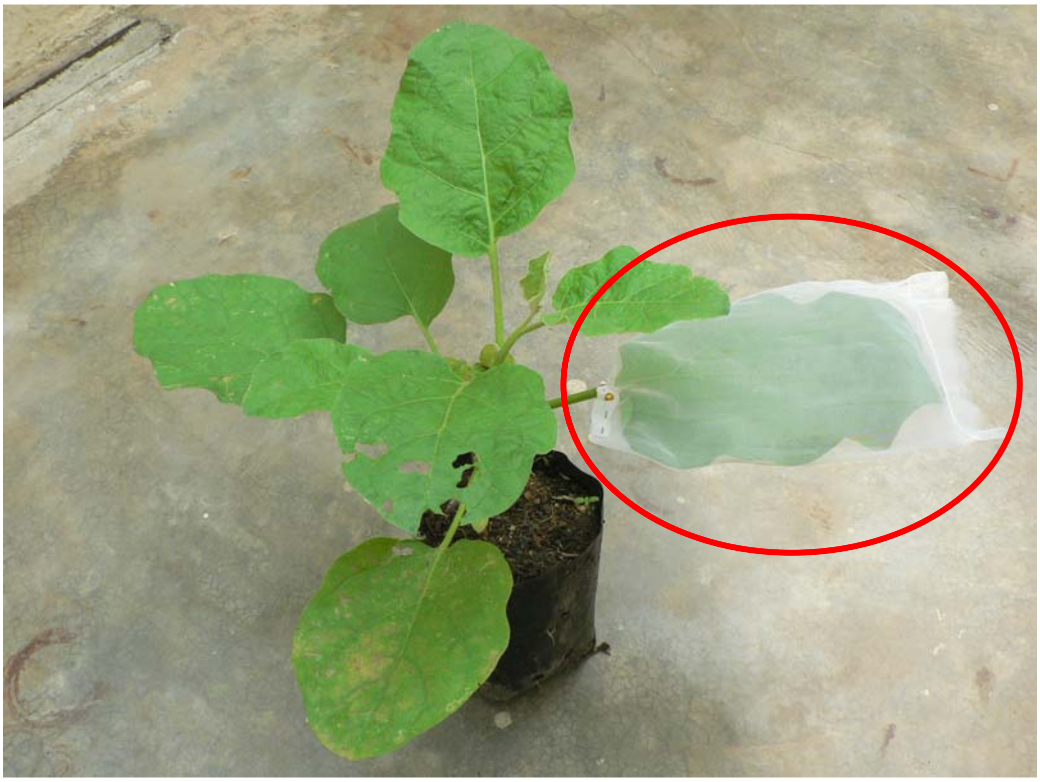


Figure 7 Adults of *Wollastoniella rotunda* Yasunaga and Miyamoto were reared on eggplant leaves which confine with fine net.

The net reproductive rate of increase (R_o) is calculated from equation:

$$R_o = \sum_{x=0}^{\alpha} l_x m_x$$

Where, 0 to α = life span

l_x = proportion at birth of females being alive at age X

m_x = number of female births during age X

$l_x m_x$ = egg curve

The cohort generation time (T_c) is calculated from the equation:

$$T_c = \sum_{x=0}^{\alpha} l_x m_x . X \Big/ \sum_{X=0}^{\alpha} l_x m_x$$

The capacity for increase (r_c) of Laughlin (1965) is as approximation of the innate capacity for increase (r_m) the calculation of which was complicated. The r_c could be calculated from the equation:

$$r_c = \log_e R_o / T_c$$

The finite rate of increase (λ) is calculated from the equation:

$$\lambda = \text{antilog}_e\ r_c$$

The egg curve was obtained by plotting $l_x m_x$ against X. This curve represented the egg schedule of births and deaths in terms of the age - schedule fecundity and probability at birth of females being alive at each age group and the egg productivity within each age group through the life history.

Partial Ecological Life Table of *Wollastoniella rotunda* Yasunaga and Miyamoto

The partial ecological life table of *W. rotunda* when fed with *T. palmi* larvae, *M. hirsutus* crawlers, *C. cephalonica* eggs and *Tetranychus* sp. adults were carried out by using newly laid eggs of *W. rotunda* on eggplant leaves from stock culture. These studies were carried out by using the same method as the biological life table. Daily observation were made and the number of individuals survived in each development stage were recorded to construct the partial ecological life table using techniques given by Napompeth (1973).

Efficiency of *Wollastoniella rotunda* Yasunaga and Miyamoto for Biological Control of *Thrips palmi* Karny

The effectiveness of *W. rotunda* under the greenhouse condition was evaluated by using 1, 2, 3 and 4 adults of *W. rotunda* for control 100 larvae of *T. palmi* on 20 eggplants. 100 *larvae* of *T. palmi* were released on the shoot, move each eggplant into the cage measuring 48 x 48 x 60 cm as shown in Figure 8. The study was carried out in the cage, and control cages were not released *W. rotunda*. The 4 x 4 completely randomize design was set for this studies. The number of *T. palmi* survived were recorded daily until *T. palmi* were exhaustion and analyzed data in the 5th day was using the Duncan's Multiple Range Test (DMRT) with SPSS for Windows Version 11.

PLACES AND DURATION

All studied were conducted in the laboratory at the National Biological Control Research Center (NBCRC), Central Regional Center (CRC), Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom during March 2005 to June 2006.

Figure 8 The cages for studies efficiency of *Wollastoniella rotunda* Yasunaga and Miyamoto.

RESULTS

Biological Studies of *Wollastoniella rotunda* Yasunaga and Miyamoto

General morphological of *W. rotunda* were not different when fed with different species of preys. General description of all stages of development were as follow.

Eggs

Eggs were laid singly in the upper or lower of eggplant leaves in the midrib of major veins. The individual was jug-shape and round oval. The newly laid eggs were creamy white and turned to red before hatching. The sizes of individual egg were not different when adults fed with *T. palmi* larvae, *C. cephalonica* eggs and *Tetranychus* sp. adults. They were 0.20 $\pm$ 0.01 mm, ranging from 0.18 to 0.20 mm in width and 0.44 $\pm$ 0.02 mm, ranging from 0.41 to 0.46 mm in length (Figure 9).

Nymphs

Newly emerged nymph was red in color and elongate-oval shaped. It had predacious behavior after emerged and invaded prey by using stylet piercing in the prey body. The second nymphal instar, dark red in color and third nymphal instar, the wing pad was appeared from the mesothorax and it was obvious in the fourth and fifth nymphal instars, in these instars the body were round-oval and more dark-red in color. All stages of nymphal instarswere shown in Figure 10.

The average size of *W. rotunda* when fed with *T. palmi* larvae, the first nymphal instar was 0.23 $\pm$ 0.01 mm, ranging from 0.20 to 0.26 mm in width and 0.51 $\pm$ 0.03 mm, ranging from 0.46 to 0.56 mm in length. The second nymphal instar was 0.32 $\pm$ 0.01 mm, ranging from 0.31

Figure 9 Eggs of *Wollastoniella rotunda* Yasunaga and Miyamoto.

Figure 10 First nymphal (A), second nymphal (B), third nymphal (C), fourth nymphal (D) and fifth nymphal (E) instars of *Wollastoniella rotunda* Yasunaga and Miyamoto.

to 0.33 mm in width and 0.65 ± 0.02 mm, ranging from 0.61 to 0.69 mm in length. The third nymphal instar was 0.42 ± 0.01 mm, ranging from 0.41 to 0.44 mm in width and 0.78 ± 0.03 mm, ranging from 0.72 to 0.80 mm in length. The fourth nymphal instar was 0.54 ± 0.01 mm, ranging from 0.54 to 0.56 mm in width and 0.92 ± 0.02 mm, ranging from 0.90 to 0.95 mm in length. And the fifth nymphal instar was 0.75 ± 0.04 mm, ranging from 0.69 to 0.79 mm in width and 1.15 ± 0.04 mm, ranging 1.08 to 1.20 mm in length.

The average size of *W. rotunda* when fed with *C. cephalonica* eggs, the first nymphal instar was 0.18 ± 0.03 mm, ranging from 0.15 to 0.20 mm in width and 0.40 ± 0.03 mm, ranging from 0.35 to 0.45 mm in length. The second nymphal instar was 0.31 ± 0.05 mm, ranging from 0.20 to 0.40 mm in width and 0.52 ± 0.05 mm, ranging from 0.45 to 0.60 mm in length. The third nymphal instar was 0.42 ± 0.04 mm, ranging from 0.35 to 0.50 mm in width and 0.69 ± 0.06 mm, ranging from 0.58 to 0.80 mm in length. The fourth nymphal instar was 0.54 ± 0.07 mm, ranging from 0.45 to 0.67 mm in width and 0.81 ± 0.08 mm, ranging from 0.60 to 0.95 mm in length. And the fifth nymphal instar was 0.76 ± 0.05 mm, ranging from 0.70 to 0.86 mm in width and 0.95 ± 0.11 mm, ranging from 0.75 to 1.14 mm in length.

The average size nymphal instars of *W. rotunda* when fed with *Tetranychus* sp. adults, the first nymphal instar was 0.25 ± 0.02 mm, ranging from 0.20 to 0.27 mm in width and 0.49 ± 0.04 mm, ranging from 0.42 to 0.54 mm in length. The second nymphal instar was 0.33 ± 0.04 mm, ranging from 0.27 to 0.43 mm in width and 0.52 ± 0.05 mm, ranging from 0.43 to 0.60 mm in length. The third nymphal instar was 0.41 ± 0.04 mm, ranging from 0.33 to 0.47 mm in width and 0.68 ± 0.04 mm, ranging from 0.60 to 0.73 mm in length. The fourth nymphal instar was 0.54 ± 0.05 mm, ranging from 0.40 to 0.60 mm in width and 0.72 ± 0.06 mm, ranging from 0.67 to 0.87 mm in length. And the fifth nymphal instar was 0.71 ± 0.06 mm, ranging from 0.60 to 0.80 mm in width and 0.98 ± 0.14 mm, ranging 0.75 to 1.18 mm in length.

Adult

The adult of *W. rotunda* was rounded, body generally blackish and small, dorsal surface densely covered with silvery and silky hair. Head was blackish or chestnut brown and shinning. Antennae were yellowish brown all four segment and thickened in female but the 3rd and 4th segments of male usually reddish brown. Pronotum, scutellum, hemelytra and abdomen were dark chestnut brown, shiny fuscous and covered with silky hair. The female was slightly larger than the male in size and could be differential by the abdomen (Figure 11).

The average size of male and female when fed with *T. palmi* larvae measured from head to terminal of fore wing were 1.26 $\pm$ 0.16 mm, ranging from 1.15 to 1.54 mm and 1.44 $\pm$ 0.09 mm, ranging from 1.33 to 1.54 mm in length; and 0.83 $\pm$ 0.11 mm, ranging from 0.74 to 1.00 mm and 0.90 $\pm$ 0.04 mm, ranging from 0.84 to 0.95 mm in width of male and female, respectively.

The average size of male and female when fed with *C. cephalonica* eggs measured from head to terminal of fore wing were 1.23 $\pm$ 0.08 mm, ranging from 1.10 to 1.36 mm and 1.41 $\pm$ 0.11 mm, ranging from 1.20 to 1.57 mm in length; and 0.70 $\pm$ 0.06 mm, ranging from 0.57 to 0.80 mm and 0.83 $\pm$ 0.04 mm, ranging from 0.75 to 0.88 mm in width of male and female, respectively.

The average size of male and female when fed with *Tetranychus* sp. adults measured from head to terminal of fore wing were 1.14 $\pm$ 0.02 mm, ranging from 1.10 to 1.15 mm and 1.20 $\pm$ 0.05 mm, ranging from 1.15 to 1.25 mm in length and 0.68 $\pm$ 0.03 mm, ranging from 0.65 to 0.70 mm and 0.77 $\pm$ 0.03 mm, ranging from 0.75 to 0.80 mm in width of male and female, respectively.

Body measurements in various stages of development of *W. rotunda* when fed with *T. palmi* larvae, *C. cephalonica* eggs and *Tetranychus* sp. adults were illustrated in Table 1, 2 and 3.

Figure 11 Male and female adults of *Wollastoniella rotunda* Yasunaga and Miyamoto.

Table 1 Body size of various stages of development of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Stage of development	Body measuring of development of *W. rotunda*			
	Mean ± S.D. (mm)		Range (mm)	
	Width	Length	Width	Length
Egg	0.20 ± 0.01	0.44 ± 0.02	0.18 - 0.20	0.41 - 0.46
Nymph				
Instar I	0.23 ± 0.01	0.51 ± 0.03	0.20 - 0.26	0.46 - 0.56
Instar II	0.32 ± 0.01	0.65 ± 0.02	0.31 - 0.33	0.61 - 0.69
Instar III	0.42 ± 0.01	0.78 ± 0.03	0.41 - 0.44	0.72 - 0.80
Instar IV	0.54 ± 0.01	0.92 ± 0.02	0.54 - 0.56	0.90 - 0.95
Instar V	0.75 ± 0.04	1.15 ± 0.04	0.69 - 0.79	1.08 - 1.20
Adult				
Male	0.83 ± 0.11	1.26 ± 0.16	0.74 – 1.00	1.15 - 1.54
Female	0.90 ± 0.04	1.44 ± 0.09	0.84 - 0.95	1.33 - 1.54

Table 2 Body size of various stages of development of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Corcyra cephalonica* (Stainton) eggs under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Stage of development	Body measuring of development of *W. rotunda*			
	Mean ± S.D. (mm)		Range (mm)	
	Width	Length	Width	Length
Egg	0.20 ± 0.01	0.44 ± 0.02	0.18 - 0.20	0.41 - 0.46
Nymph				
Instar I	0.18 ± 0.03	0.40 ± 0.03	0.15 - 0.20	0.35 - 0.45
Instar II	0.31 ± 0.05	0.52 ± 0.05	0.20 - 0.40	0.45 - 0.60
Instar III	0.42 ± 0.04	0.69 ± 0.06	0.35 - 0.50	0.58 - 0.80
Instar IV	0.54 ± 0.07	0.81 ± 0.08	0.45 - 0.67	0.60 - 0.95
Instar V	0.76 ± 0.05	0.95 ± 0.11	0.70 - 0.86	0.75 - 1.14
Adult				
Male	0.70 ± 0.06	1.23 ± 0.08	0.57 - 0.80	1.10 - 1.36
Female	0.83 ± 0.04	1.41 ± 0.11	0.75 - 0.88	1.20 - 1.57

Table 3 Body size of various stages of development of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Tetranychus* sp. adults under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Stage of development	Body measuring of development of *W. rotunda*			
	Mean ± S.D. (mm)		Range (mm)	
	Width	Length	Width	Length
Egg	0.20 ± 0.01	0.44 ± 0.02	0.18 - 0.20	0.41 - 0.46
Nymph				
Instar I	0.25 ± 0.02	0.49 ± 0.04	0.20 - 0.27	0.42 - 0.54
Instar II	0.33 ± 0.04	0.52 ± 0.05	0.27 - 0.43	0.43 - 0.60
Instar III	0.41 ± 0.04	0.68 ± 0.04	0.33 - 0.47	0.60 - 0.73
Instar IV	0.54 ± 0.05	0.72 ± 0.06	0.40 - 0.60	0.67 - 0.87
Instar V	0.71 ± 0.06	0.98 ± 0.14	0.60 - 0.80	0.75 - 1.18
Adult				
Male	0.68 ± 0.03	1.14 ± 0.02	0.65 - 0.70	1.10 - 1.15
Female	0.77 ± 0.03	1.20 ± 0.05	0.75 - 0.80	1.15 - 1.25

The average sized of *W. rotunda* which fed on *C. cephalonica* eggs sizes was smaller than fed on *T. palmi* larvae but it was not significant different when fed on *Tetranychus* sp. adults as shown in Table 4.

Duration of Developmental Stages of *Wollastoniella rotunda* Yasunaga and Miyamoto

The duration period of stages of *W. rotunda* when fed with *T. palmi* larvae under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH) was shown in Table 5, the incubation period was 5.50 $\pm$ 0.51 days, ranging from 5 to 6 days. Nymphal stage of *W. rotunda* was consisted of five instars. The first nymphal instar was 2.20 $\pm$ 0.41 days, ranging from 2 to 3 days. The second nymphal instar was 2.26 $\pm$ 0.07 days, ranging from 2 to 3 days. The third nymphal instar was 2.00 $\pm$ 0.69 days, ranging from 1 to 4 days. The fourth nymphal instar was 2.94 $\pm$ 0.43 days, ranging from 2 to 4 days. The fifth nymphal instar was 4.76 $\pm$ 0.75 days, ranging from 4 to 6 days. The total period of nymphal stage was 14.12 $\pm$ 1.22 days, ranging from 12 to 17 days. The average longevity of male was 10.13 $\pm$ 4.19 days, ranging from 4 to 15 days. The longevity of females was 16.67 $\pm$ 7.84 days, ranging from 5 to 28 days. The average total life cycle of male was 29.50 $\pm$ 4.38 days, ranging from 22 to 35 days, and female was 36.00 $\pm$ 6.51 days, ranging from 26 to 45 days.

Duration stages of *W. rotunda* when fed with *C. cephalonica* eggs days under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$2 % RH) was shown in Table 6, the incubation period was 5.85 $\pm$ 0.37 days, ranging from 5 to 6 days. Nymphal stage of *W. rotunda* was consisted of five instars. The first nymphal instar was 3.00 $\pm$ 0.79 days, ranging from 2 to 6 days. The second nymphal instar was 2.75 $\pm$ 0.30 days, ranging from 1 to 6 days. The third nymphal instar was 2.72 $\pm$ 0.89 days, ranging from 2 to 5 days. The fourth nymphal instar was 2.53 $\pm$ 0.62 days, ranging from 2 to 4 days. The fifth nymphal instar was 5.00 $\pm$ 1.22 days, ranging from 4 to 9 days. The total period of nymphal stage was 15.76 $\pm$ 2.88 days, ranging from 13 to 24 days. The average longevity of male was 4.88 $\pm$ 2.17 days, ranging from 2 to 9 days. The average longevity of female was 5.00 $\pm$ 2.10 days, ranging from 1 to 7 days. The total life cycle of male was 26.00

Table 4 Analysis body measuring of *Wollastoniella rotunda* Yasunaga and Miyamoto in each stages when fed with *Thrips palmi* Karny larvae, *Corcyra cephalonica* (Stainton) eggs and *Tetranychus* sp. adults under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Food Stuff	**1st Nymph**		**2nd Nymph**		**3rd Nymph**		**4th Nymph**		**5th Nymph**		**Male**		**Female**	
	Width	**Length**	**Width**	**Length**	**Width**	**Length**	**Width**	**Length**	**Width**	**Length**	**Width**	**Length**	**Width**	**Length**
Larvae of *T. palmi*	0.23 a**	0.51 a	0.32 a	0.65 a	0.42 a*	0.78 a	0.54 a	0.92 a	0.75 a	1.15 a	0.83 a	1.26 ab	0.90 a	1.44 a
Eggs of *C. cephalonica*	0.18 a	0.40 ab	0.31 ab	0.52 b	0.42 a	0.69 b	0.54 a	0.81 b	0.76 a	0.95 b	0.70 b	1.23 a	0.83 b	1.41 a
Adults of *Tetranychus* sp.	0.25 b	0.49 b	0.33 b	0.52 c	0.41 a	0.68 b	0.54 a	0.72 c	0.71 b	0.98 b	0.68 b	1.44 b	0.77 b	1.20 b

*   Mean followed by the same alphabets in a column are not significantly different at 95% (p > 0.05) by using the Duncan's Multiple Range Test (DMRT)

** Mean followed by the different alphabets in a column are significantly different at 95% (p < 0.05) by using the Duncan's Multiple Range Test (DMRT)

Table 5 Duration of various developmental stages of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae under laboratory condition ($28 \pm 2\ ^{o}C$ and 75 ± 2 % RH).

Stage of development	N	Mean $\pm$ S.D. (days)	Range (days)
Egg :	20	5.50 $\pm$ 0.51	5 - 6
Nymph :			
Instar I	20	2.20 $\pm$ 0.41	2 - 3
Instar II	19	2.26 $\pm$ 0.07	2 - 3
Instar III	18	2.00 $\pm$ 0.69	1 - 4
Instar IV	18	2.94 $\pm$ 0.43	2 - 4
Instar V	17	4.76 $\pm$ 0.75	4 - 6
Total nymphal period :	17	14.12 $\pm$ 1.22	12 - 17
Adult :			
Male	7	10.13 $\pm$ 4.19	4 - 15
Female	7	16.67 $\pm$ 7.84	5 - 28
Total life cycle :			
Male	7	29.50 $\pm$ 4.38	22 - 35
Female	7	36.00 $\pm$ 6.51	26 - 45

Table 6 Duration of various developmental stages of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Corcyra cephalonica* (Stainton) eggs under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Stage of development	N	Mean $\pm$ S.D. (days)	Range (days)
Egg :	20	5.85 $\pm$ 0.37	5 - 6
Nymph :			
Instar I	20	3.00 $\pm$ 0.79	2 - 6
Instar II	20	2.75 $\pm$ 0.30	1 - 6
Instar III	18	2.72 $\pm$ 0.89	2 - 5
Instar IV	17	2.53 $\pm$ 0.62	2 - 4
Instar V	17	5.00 $\pm$ 1.22	4 - 9
Total nymphal period :	17	15.76 $\pm$ 2.88	13 - 24
Adult :			
Male	8	4.88 $\pm$ 2.17	2 - 9
Female	6	5.00 $\pm$ 2.10	1 - 7
Total life cycle :			
Male	8	26.00 $\pm$ 3.42	23 - 34
Female	6	26.50 $\pm$ 2.07	25 - 30

± 3.42 days, ranging from 23 to 34 days, and females was 26.50 ± 2.07 days, ranging from 25 to 30 days.

Duration stages of *W. rotunda* when fed with *Tetranychus* sp. adults under laboratory condition (28 ± 2 ^{o}C and 75 ± 2 % RH) was shown in Table 7, the incubation period was 5.15 ± 0.37 days, ranging from 5 to 6 days. Nymphal stage of *W. rotunda* was consisted of five instars. The first nymphal instar was 3.05 ± 1.19 days, ranging from 2 to 7 days. The second nymphal instar was 3.00 ± 1.41 days, ranging from 2 to 7 days. The third nymphal instar was 2.75 ± 1.12 days, ranging from 2 to 6 days. The fourth nymphal instar was 2.85 ± 0.93 days, ranging from 1 to 5 days. The fifth nymphal instar was 5.59 ± 2.21 days, ranging from 4 to 12 days. The total period of nymphal stage was 16.82 ± 3.13 days, ranging from 13 to 23 days. The average longevity of male was 10.14 ± 7.40 days, ranging from 2 to 21 days. The average longevity of female was 14.14 ± 7.76 days, ranging from 4 to 23 days. The total life cycle of male was 31.43 ± 7.98 days, ranging from 21 to 40 days, and female was 36.71 ± 7.54 days, ranging from 27 to 45 days.

Duration stages of *W. rotunda* when fed with different species of prey was not different in nymphal stage but the duration stage of adult when fed with *T. palmi* larvae and *Tetranychu*s sp. adults higher than fed with *C. cephalonica* eggs as shown in Table 8.

Biological Life Table of *Wollastoniella rotunda* Yasunaga and Miyamoto

The biological life table of *W. rotunda* was investigated and constructed when fed with *T. palmi* larvae as shown in Table 9. The population statistics were calculated, various population parameters calculated from this table were the net reproductive rate of increase (R_o) was 6.7067, the capacity for increase (r_c) was 0.0641, the finite rate of increase (λ) was 1.0662 and the cohort generation time (T_c) was 29.6750 days (Table 10). From these parameters indicated that the population of *W. rotunda* could multiply 6.7067 times in each generation or the population could multiply 1.0662 times in three days and the mean length of a generation time was 29.6750 days.

Table 7 Duration of various developmental stages of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Tetranychus* sp. adults under laboratory condition ($28 \pm 2\ ^{o}C$ and 75 ± 2 % RH).

Stage of development	N	Mean $\pm$ S.D. (days)	Range (days)
Egg :	20	5.15 $\pm$ 0.37	5 - 6
Nymph :			
Instar I	20	3.05 $\pm$ 1.19	2 - 7
Instar II	19	3.00 $\pm$ 1.41	2 - 7
Instar III	18	2.75 $\pm$ 1.12	2 - 6
Instar IV	18	2.85 $\pm$ 0.93	1 - 5
Instar V	17	5.59 $\pm$ 2.21	4 - 12
Total nymphal period :	17	16.82 $\pm$ 3.13	13 - 23
Adult :			
Male	7	10.14 $\pm$ 7.40	2 - 21
Female	7	14.14 $\pm$ 7.76	4 - 23
Total life cycle :			
Male	7	31.43 $\pm$ 7.98	21 - 40
Female	7	36.71 $\pm$ 7.54	27 - 45

Table 8 Comparative of duration period of *Wollastoniella rotunda* Yasunaga and Miyamoto in each stages when fed with *Thrips palmi* Karny larvae, *Corcyra cephalonica* (Stainton) eggs and *Tetranychus* sp. adults under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Food Stuff	**1st Nymph** Mean $\pm$ S.D. (days)	**2nd Nymph** Mean $\pm$ S.D. (days)	**3rd Nymph** Mean $\pm$ S.D. (days)	**4th Nymph** Mean $\pm$ S.D. (days)	**5th Nymph** Mean $\pm$ S.D. (days)	**Total Nymph** Mean $\pm$ S.D. (days)	**Male** Mean $\pm$ S.D. (days)	**Female** Mean $\pm$ S.D. (days)
Larva of *T. palmi*	2.20 $\pm$ 0.41 a *	2.26 $\pm$ 0.07 a	2.00 $\pm$ 0.69 a	2.94 $\pm$ 0.43 a	4.76 $\pm$ 0.75 a	14.12 $\pm$ 1.22 a	10.13 $\pm$ 4.19 a **	16.67 $\pm$ 7.84 a
Egg of *C. cephalonica*	3.00 $\pm$ 0.79 a	2.75 $\pm$ 0.30 a	2.72 $\pm$ 0.89 a	2.53 $\pm$ 0.62 a	5.00 $\pm$ 1.22 a	15.76 $\pm$ 2.88 a	4.88 $\pm$ 2.17 b	5.00 $\pm$ 2.10 b
Adult of *Tetranychus* sp.	3.05 $\pm$ 1.19 a	3.00 $\pm$ 1.41 a	2.75 $\pm$ 1.12 a	2.85 $\pm$ 0.93 a	5.59 $\pm$ 2.21 a	16.82 $\pm$ 3.13 a	10.14 $\pm$ 7.40 a	14.14 $\pm$ 7.76 a

* Mean followed by the same alphabets in a column are not significantly different at 95% ($p > 0.05$) by using the Duncan's Multiple Range Test (DMRT)

** Mean followed by the different alphabets in a column are significantly different at 95% ($p < 0.05$) by using the Duncan's Multiple Range Test (DMRT)

Table 9 Biological life table, age-specific fecundity rate and net reproductive rate of increase (R_o) of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Pivotal age in days (X)	Proportion at birth of female Being alive stage (X) (l_x) [1/]	Age-specific fecundity (Eegg/ E/ X) (m_x) [2/]	Egg-curve ($l_x m_x$) [3/]	$l_x m_x . X$
0	0.0000	-	Immature stages	-
3	0.0000	-		-
6	0.8033	-		-
9	0.8233	-		-
12	0.5500	-		-
15	0.4967	-		-
18	0.4200	-		-
21	0.3267	1.4596	0.4767	10.0100
24	0.3633	2.7523	1.0000	24.0000
27	0.2233	8.7910	1.9633	53.0100
30	0.1867	6.2500	1.1677	35.0000
33	0.1133	6.6765	0.7567	24.9700
36	0.0667	9.8000	0.6533	23.5200
39	0.0467	7.7857	0.3633	14.1700
42	0.0367	3.5455	0.1300	5.4600
45	0.0200	9.3333	0.1867	8.4000
48	0.0100	1.0000	0.0100	0.4800
		$R_o = \Sigma l_x m_x$ =	6.7067	

[1/] l_x = The probability of individual being alive at the beginning of the age - interval.

[2/] m_x = The number of female eggs or off - springs for each age - interval.

[3/] $l_x m_x$ = After Laughlin (1965).

Table 10 Biological attributes of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Biological attribute	**Calculated value**
Net reproductive rate of increase (R_o)	6.7067
Capacity for increase (r_c)	0.0641
Finite rate of increase (λ)	1.0662
Cohort generation time (T_c)	29.6750

The egg curve of *W. rotunda* when fed with *T. palmi* larvae constructed by plotted $l_x m_x$ againt (Figure 12). The oviposition period was about 27 days when fed with *T. palmi* larvae. The number of eggs laid was maximized in the 9^{th} days.

The biological life table of *W. rotunda* was investigated and constructed when fed with *M. hirsutus* crawlers as shown in Table 11. The population statistics was calculated, various population parameters calculated from this table was the net reproductive rate of increase (R_o) was 0. This indicated that *W. rotunda* could not produced eggs when fed with *M. hirsutus* crawlers.

The biological life table of *W. rotunda* was investigated and constructed when fed with *C. cephalonica* eggs as shown in Table 12. The population statistics was calculated, various population parameters calculated from this table was the net reproductive rate of increase (R_o) was 0.1400, the capacity for increase (r_c) was - 0.0760, the finite rate of increase (λ) was 0.9971 and the cohort generation time (T_c) was 25.8571 days (Table 13). From these parameters indicated that the population of *W. rotunda* could multiply 0.1400 times in each generation or the population could multiply 0.9971 times in three days and the mean length of a generation time was 25.8571 days.

The egg curve of *W. rotunda* when fed with *C. cephalonica* eggs constructed by plotted $l_x m_x$ againt (Figure 13). The oviposition period was about 9 days when fed with *C. cephalonica* eggs. The number of eggs laid was maximized in the 6^{th} days.

The biological life table of *W. rotunda* was investigated and constructed when fed with *Tetranychus* sp. adults as shown in Table 14. The population statistics was calculated, various population parameters calculated from this table was the net reproductive rate of increase (R_o) was 9.3533, the capacity for increase (r_c) was 0.0535, the finite rate of increase (λ) was 1.0550 and the cohort generation time (T_c) was 41.7819 days (Table 15). From these parameters indicated that the population of *W. rotunda* could multiply 9.3533 times in each generation or the

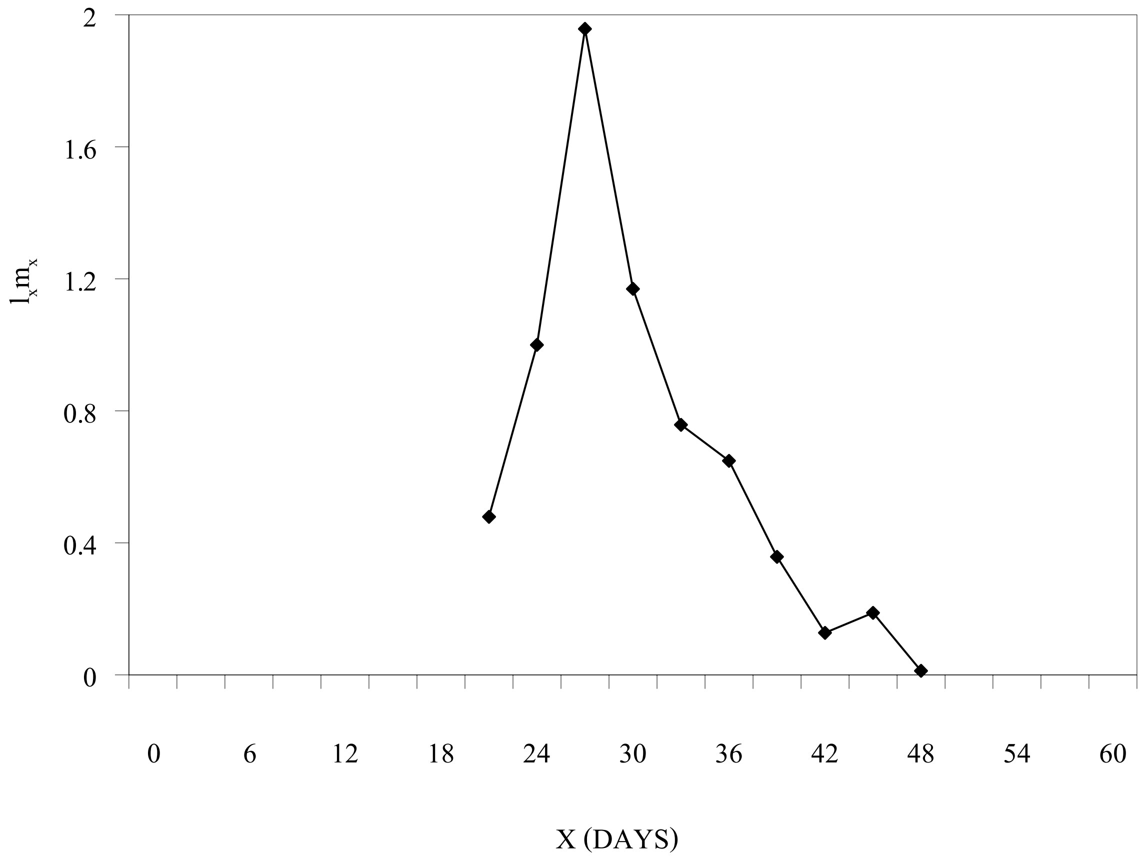


Figure 12 Egg curve of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Table 11 Biological life table, age-specific fecundity rate and net reproductive rate of increase (R_o) of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Maconellicoccus hirsutus* (Green) crawlers under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Pivotal age in days (X)	Proportion at birth of female Being alive stage (X) (l_x) [1/]	Age-specific fecundity (Eegg/ E/ X) (m_x) [2/]	Egg-curve ($l_x m_x$) [3/]	$l_x m_x . X$
0	1.0000	-	Immature stages	-
3	0.0000	-		-
6	0.9400	-		-
9	0.1900	-		-
12	0.0233	-		-
15	0.0000	-		-
		$R_o = \Sigma l_x m_x$	= 0.0000	

[1/] l_x = The probability of individual being alive at the beginning of the age-interval.

[2/] m_x = The number of female eggs or off - springs for each age - interval.

[3/] $l_x m_x$ = After Laughlin (1965).

Table 12 Biological life table, age-specific fecundity rate and net reproductive rate of increase (R_o) of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Corcyra cephalonica* (Stainton) eggs under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Pivotal age in days (X)	Proportion at[1/] birth of female Being alive stage (X) (l_x)	Age-specific[2/] fecundity (Eegg/ E/ X) (m_x)	Egg-curve[3/] ($l_x m_x$)	$l_x m_x . X$
0	1.0000	-	Immature stages	-
3	0.0000	-		-
6	0.8833	-		-
9	0.7833	-		-
12	0.6133	-		-
15	0.4867	-		-
18	0.4200	-		-
21	0.2333	-		-
24	0.1267	0.5000	0.0633	1.5200
27	0.0500	1.3333	0.0667	1.8000
30	0.0300	0.3333	0.0100	0.3000
33	0.0033	0.0000	0.0000	0.0000
36	0.0033	0.0000	0.0000	0.0000
		$R_o = \Sigma l_x m_x$ =	0.1400	

[1/] l_x = The probability of individual being alive at the beginning of the age-interval.

[2/] m_x = The number of female eggs or off - springs for each age - interval.

[3/] $l_x m_x$ = After Laughlin (1965).

Table 13 Biological attributes of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Corcyra cephalonica* (Stainton) eggs under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Biological attribute	Calculated value
Net reproductive rate of increase (R_o)	0.1400
Capacity for increase (r_c)	- 0.0760
Finite rate of increase (λ)	0.9971
Cohort generation time (T_c)	25.8571

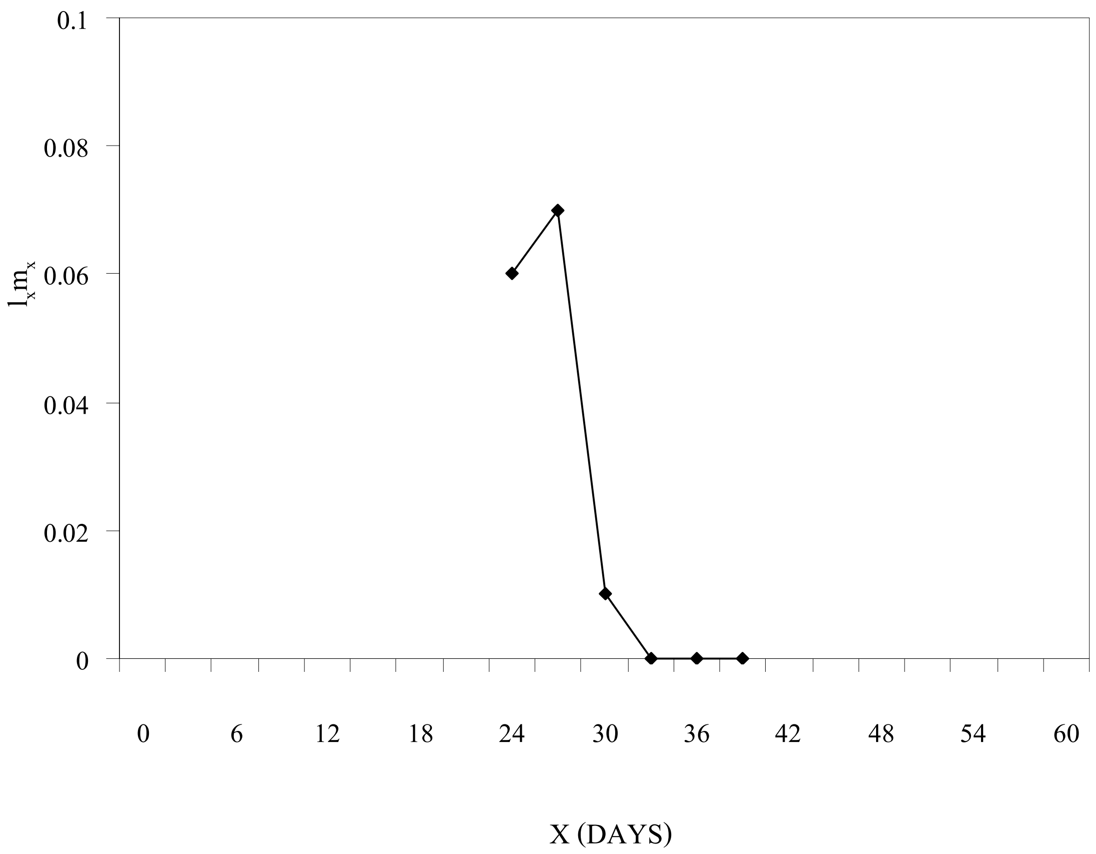


Figure 13 Egg curve of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Corcyra cephalonica* (Stainton) eggs under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Table 14 Biological life table, age-specific fecundity rate and net reproductive rate of increase (R_o) of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Tetranychus* sp. adults under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Pivotal age in days (X)	Proportion at birth of female Being alive stage (X) (l_x) [1/]	Age - specific fecundity (Eegg/ E/ X) (m_x) [2/]	Egg-curve ($l_x m_x$) [3/]	$l_x m_x . X$
0	1.0000	-	Immature stages	-
3	0.0000	-		-
6	0.8867	-		-
9	0.8333	-		-
12	0.5867	-		-
15	0.5467	-		-
18	0.5133	-		-
21	0.4400	-	-	-
24	0.3800	-	-	-
27	0.3600	0.5926	0.2133	5.7600
30	0.2467	2.7027	0.6667	20.0000
33	0.2400	2.9722	0.7133	23.5400
36	0.2400	5.1944	1.2467	44.8800
39	0.2133	3.2500	0.6933	27.0400
42	0.2000	8.2667	1.6533	69.4400
45	0.2000	7.8000	1.5600	70.2000
48	0.1667	8.1600	1.3600	65.2800
51	0.1667	5.4800	0.9133	46.5800
54	0.0800	3.8333	0.3067	16.5600
57	0.0467	0.5714	0.0267	1.5200
60	0.0133	0.0000	0.0133	0.8000
		$R_o = \Sigma l_x m_x$	= 9.3533	

[1/] l_x = The probability of individual being alive at the beginning of the age - interval.

[2/] m_x = The number of female eggs or off - springs for each age - interval.

[3/] $l_x m_x$ = After Laughlin (1965).

Table 15 Biological attributes of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Tetranychus* sp. adults under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Biological attribute	**Calculated value**
Net reproductive rate of increase (R_o)	9.3533
Capacity for increase (r_c)	0.0535
Finite rate of increase (λ)	1.0550
Cohort generation time (T_c)	41.7819

population could multiply 1.0550 times in three days and the mean length of a generation time was 41.7819 days.

The egg curve of *W. rotunda* when fed with *Tetranychus* sp. adults constructed by plotted $l_x m_x$ againt (Figure 14). The oviposition period was about 33 days when fed with *Tetranychus* sp. adults. The period number of eggs laid was maximum productivity occurred during the 12^{th} to 18^{st} days and the egg was decline after that.

From the investigation on biological life table revealed that the net reproductive rate of increase (R_o) and the cohort generation time (T_c) was highest when fed with *Tetranychus* sp. adults, and the capacity for increase (r_c) and the finite rate of increase (λ) was highest when fed with *T. palmi* larvae as shown in Table 16.

<u>Partial Ecological Life Table of *Wollastoniella rotunda* Yasunaga and Miyamoto</u>

The partial ecological life table was constructed using laboratory life history data. It was an indicator of the innate mortality and not to other mortality factors. The survivorship curves of *W. rotunda* when fed with different preys were constructed by using the number of individuals survived in each development stages.

The partial ecological life table of *W. rotunda* when fed with *T. palmi* larvae was illustrated in Table 17. It was obvious that the mortality in the first nymph was 87 percent. The survivorship curve, as shown in Figure 15, indicated high mortality during the first instar nymphs. The mortality was less during the third nymphal instar.

The partial ecological life table of *W. rotunda* when fed with *M. hirsutus* crawlers was illustrated in Table 18. It was obvious that the mortality in the third instar nymph was 100 percent. The survivorship curve, as shown in Figure 16, indicated high mortality during the second and third instar nymphs. *W. rotunda* could not develop and survived to the fourth nymphal instar.

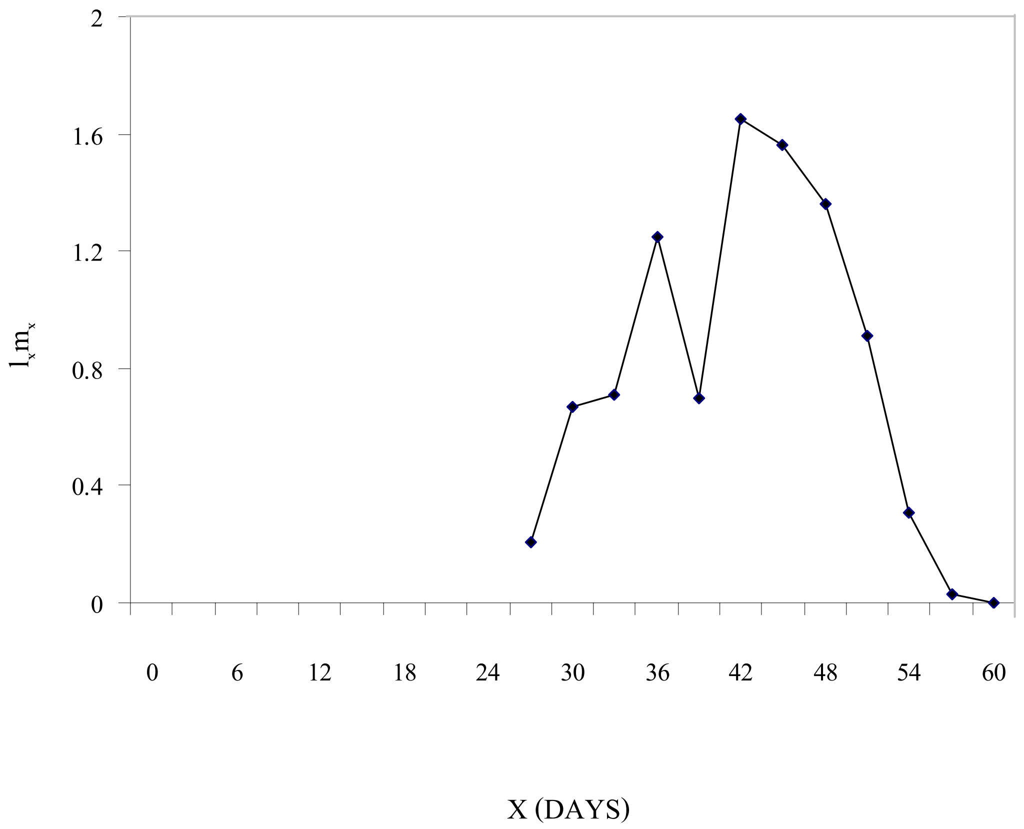


Figure 14 Egg curve of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Tetranychus* sp. adults under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Table 16 Population parameters calculated from biological attributes of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae, *Maconellicoccus hirsutus* (Green) crawlers, *Corcyra cephalonica* (Stainton) eggs and *Tetranychus* sp. adults.

Biological attribute	**Preys species**			
	Thrips palmi	*Maconellicoccus hirsutus*	*Corcyra cephalonica*	*Tetranychus* sp.
Net reproductive rate of increase (R_o)	6.7067	0	0.1400	9.3533
Capacity for increase (r_c)	0.0641	-	- 0.0760	0.0535
Finite rate of increase (λ)	1.0662	-	0.9971	1.0550
Cohort generation time (T_c)	29.6750	-	25.8571	41.7819

Table 17 Partial ecological life table of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Stage of development (X)	No. surviving in X (l_x)	No. dying in X (d_x)	Percent mortality (100 q_x)	Generation mortality (100 d_x /n)
Egg :	300	17	5.6667	5.6667
Nymph :				
Instar I	283	87	30.7420	29.0000
Instar II	196	33	16.8367	11.0000
Instar III	163	6	3.6810	2.0000
Instar IV	157	11	7.0064	3.6667
Instar V	146	34	23.2877	11.3333
Adult :	112	-	-	-

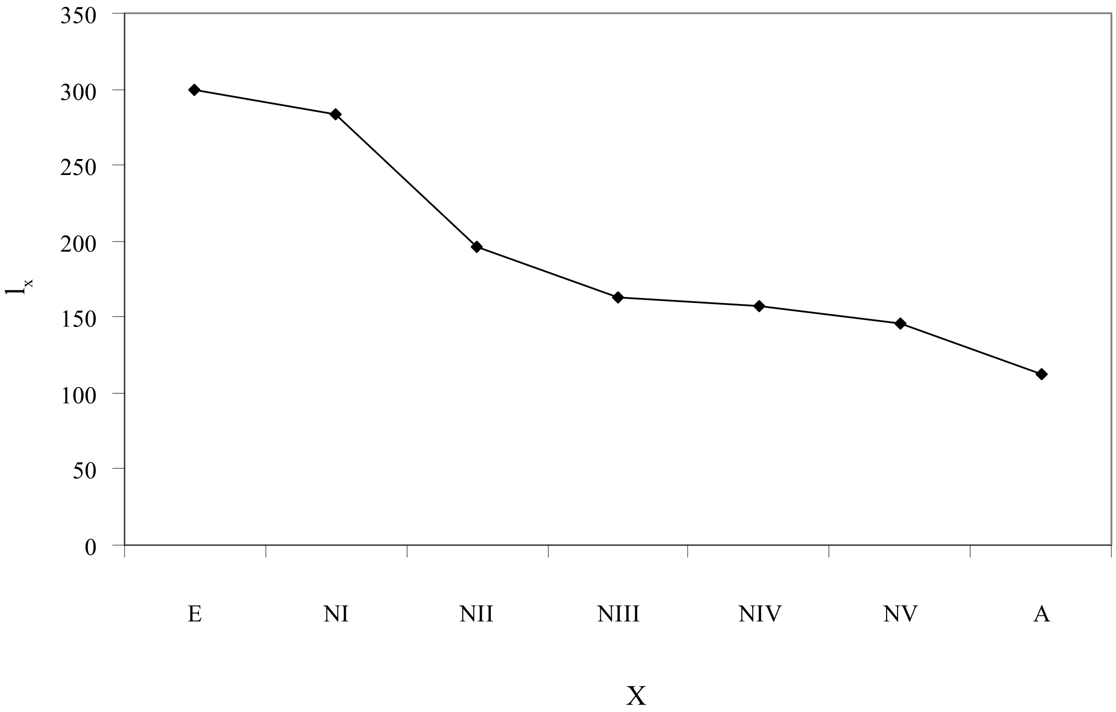


Figure 15 Survivorship curve of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Thrips palmi* Karny larvae laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Table 18 Partial ecological life table of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Maconellicoccus hirsutus* (Green) crawlers under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Stage of development (X)	No. surviving in X (l_x)	No. dying in X (d_x)	Percent mortality (100 q_x)	Generation mortality (100 d_x /n)
Egg :	300	18	6.1111	6.1111
Nymph :				
Instar I	282	140	49.7041	46.6667
Instar II	142	122	85.8824	40.5556
Instar III	20	20	100.0000	6.6667
Instar IV	0	0	0.0000	0.0000
Instar V	0	0	0.0000	0.0000
Adult :	0	-	-	-

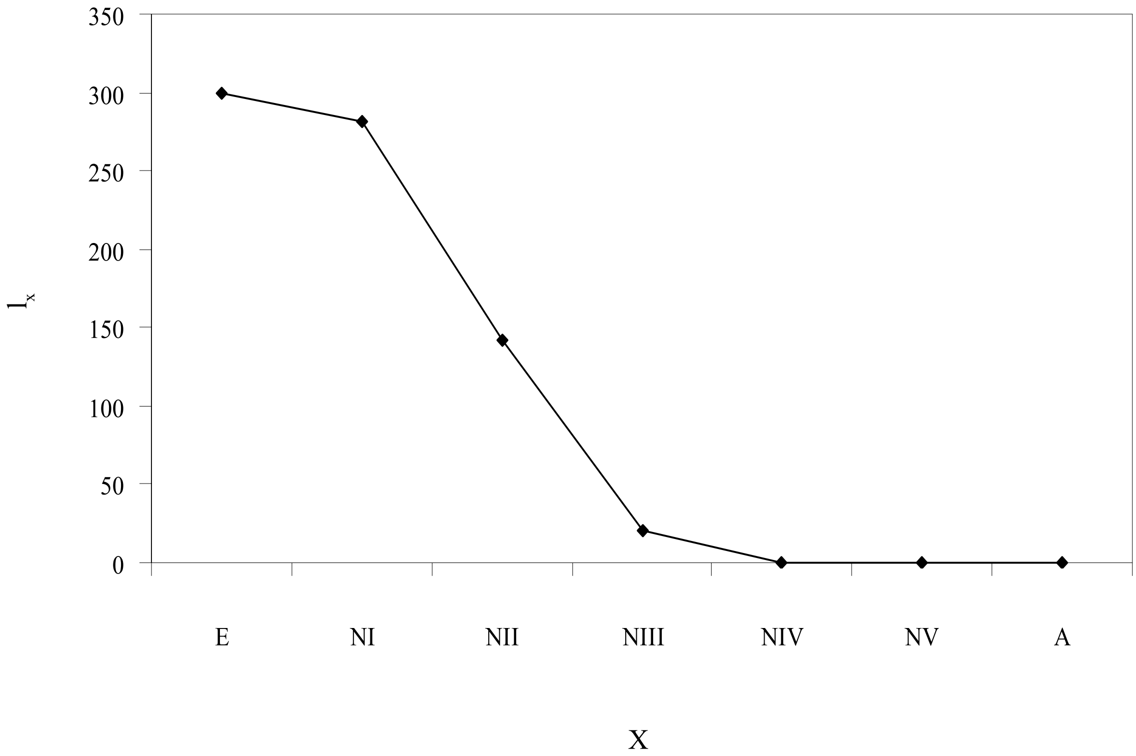


Figure 16 Survivorship curve of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Maconellicoccus hirsutus* (Green) crawlers under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

The partial ecological life table of *W. rotunda* when fed with *C. cephalonica* eggs was illustrated in Table 19. It was obvious that the mortality in the fifth nymph was 65 percent. The survivorship curve, as shown in Figure 17, indicated high mortality during the third and fifth instar nymphs. The mortality was less during the fourth nymphal instar.

The partial ecological life table of *W. rotunda* when fed with *Tetranychus* sp. adults was illustrated in Table 20. From the table the mortality in the first nymph was more than 70 percent. The survivorship curve was shown in Figure 18. It indicated that high mortality occurred during the earlier stages of development after that the mortality slightly declined. The mortality was high during the fifth nymph and it was less during the fourth nymphal instar.

Efficiency of *Wollastoniella rotunda* Yasunaga and Miyamoto for biological control of *Thrips palmi* Karny

The efficiency of *W. rotunda* was evaluated by counting the number of survived *T. palmi* in the cage after released 1, 2, 3 and 4 adult of *W. rotunda* for controlled 100 larvae of *T. palmi*. The numbers of *T. palmi* that survived was shown in Figure 19. It indicated that *W. rotunda* could control *T.palmi* until it was exhausted in 5, 6, 8 and 9 days, respectively. In the control cage, the number of *T. palmi* was decreased in the fifth day and then they was increased and higher than in released cage. Efficiency of 2, 3 and 4 adults of *W. rotunda* were not significant different, 1 and 2 adults of *W. rotunda* were not significant different for controlling 100 larvae of *T. palmi* but 1 adults of *W. rotunda* was different with 3 and 4 adults of *W. rotunda* for controlling 100 larvae of *T. palmi* as shown in Table 21.

Table 19 Partial ecological life table of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Corcyra cephalonica* (Stainton) eggs under laboratory condition (28 ± 2 °C and 75 ± 2 % RH).

Stage of development (X)	No. surviving in X (l_x)	No. dying in X (d_x)	Percent mortality (100 q_x)	Generation mortality (100 d_x /n)
Egg :	300	36	12.1622	12.1622
Nymph :				
Instar I	264	47	17.6597	15.5405
Instar II	217	47	21.4846	15.54.5
Instar III	170	59	34.5787	19.5946
Instar IV	111	22	20.0877	7.4324
Instar V	89	65	72.8819	21.6216
Adult :	24	-	-	-

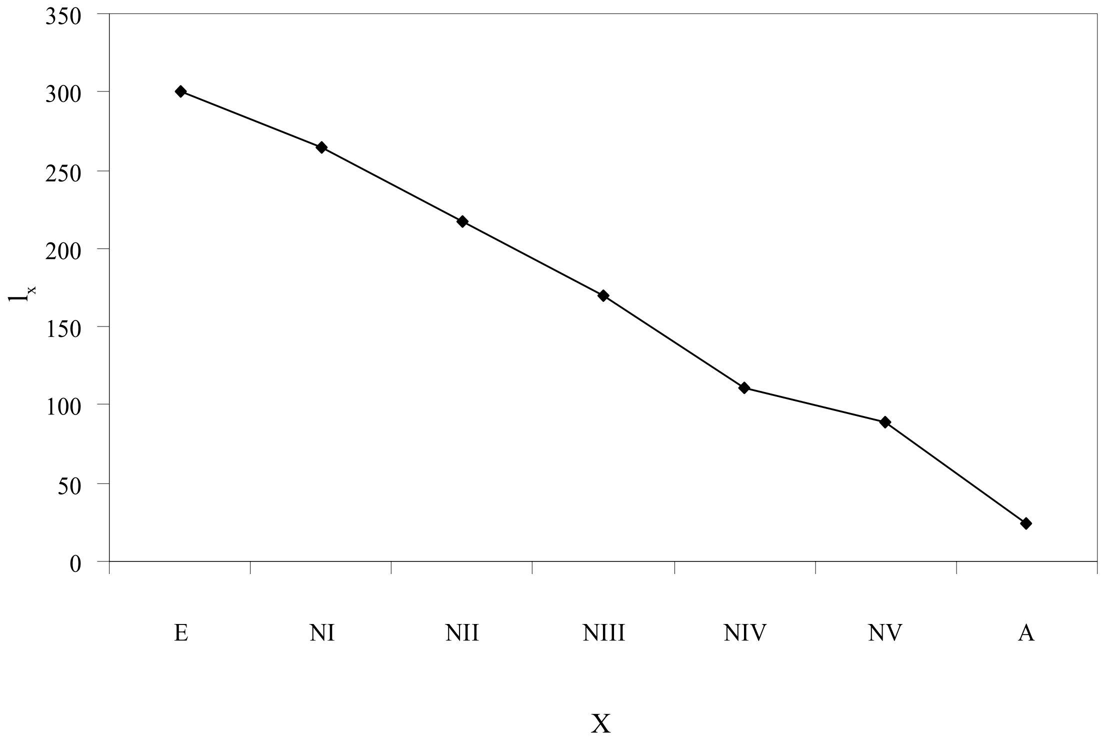


Figure 17 Survivorship curve of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Corcyra cephalonica* (Stainton) eggs laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Table 20 Partial ecological life table of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Tetranychus* sp. adults under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).

Stage of development (X)	No. surviving in X (l_x)	No. dying in X (d_x)	Percent mortality (100 q_x)	Generation mortality (100 d_x /n)
Egg :	300	21	6.9930	6.9930
Nymph :				
Instar I	279	73	26.3178	24.4755
Instar II	206	25	12.2208	8.3916
Instar III	180	10	5.8275	3.4965
Instar IV	170	31	18.5109	10.4895
Instar V	138	44	31.9246	14.6853
Adult :	94	-	-	-

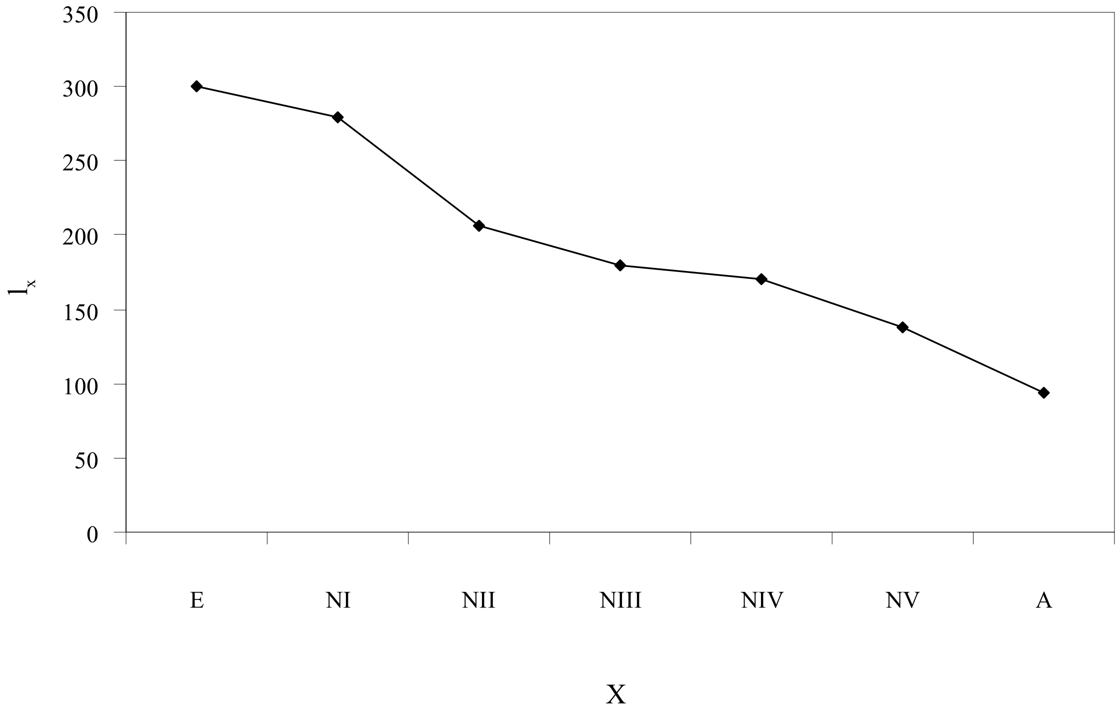
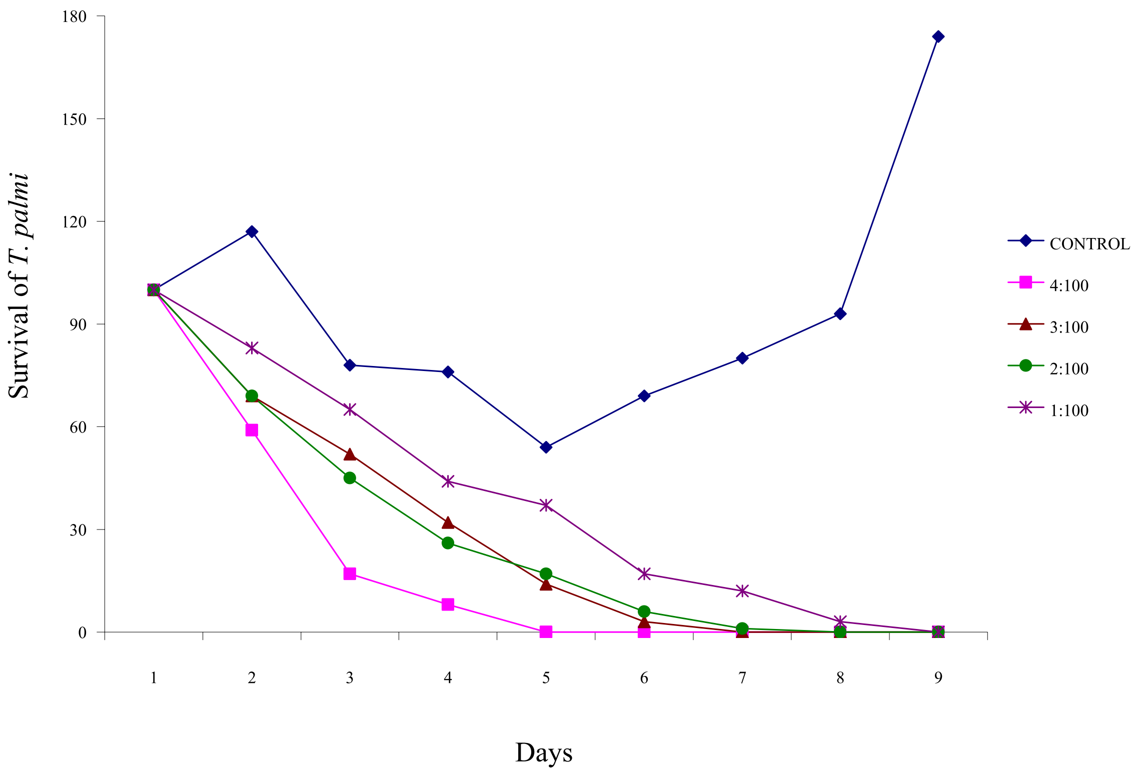


Figure 18 Survivorship curve of *Wollastoniella rotunda* Yasunaga and Miyamoto when fed with *Tetranychus* sp adults laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH).



<u>Figure 19</u> Efficiency of *Wollastoniella rotunda* Yasunaga and Miyamoto when released on different rates for controlling *Thrips palmi* Karny in the cage.

Table 21 Efficiency of *Wollastoniella rotunda* Yasunaga and Miyamoto when released on different rates for controlling *Thrips palmi* Karny in the cage (the 5th day).

Rate of *W. rotunda* for controled *T. palmi* (*W. rotunda* : *T. palmi*)	Survival of *T. palmi* in the 5th day (Mean ± S.D.)	
Control	80.00 ± 47.77	a
1 : 100	17.25 ± 15.95	b
2 : 100	5.75 ± 8.50	bc
3 : 100	3.25 ± 7.51	c
4 : 100	0	c

* Mean followed by the same alphabets in a column are not significantly different at 95% ($p > 0.05$) by using the Duncan's Multiple Range Test (DMRT)

** Mean followed by the different alphabets in a column are significantly different at 95% ($p < 0.05$) by using the Duncan's Multiple Range Test (DMRT)

DISCUSSION

The study on biology of *W. rotunda* feeding with *T. palmi* larvae in laboratory conditions at 28 $\pm$ 2 ^{o}C and 75 % RH revealed that egg incubation period was 5 - 6 days. The duration of five nymphal instars was 2.20 $\pm$ 0.41, 2.26 $\pm$ 0.07, 2.00 $\pm$ 0.69, 2.94 $\pm$ 0.43 and 4.76 $\pm$ 0.75 days, respectively. The longevity of male and female adults was 4 - 15 and 5 - 28 days, respectively. The results obtained from this study similar to the study of Rattanaka (2003) who reported that the incubation period was 6 - 7 days. The duration of five nymphal instars was 2.20 $\pm$ 0.41, 2.26 $\pm$ 0.45, 2.00 $\pm$ 0.69, 2.94 $\pm$ 0.43 and 4.76 $\pm$ 0.75 days, respectively. The longevity of male and female adults was 4 - 14 and 5 - 28 days, respectively in laboratory condition at 28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH. Napompeth *et al*., (1996) they reported that incubation period was 7 - 9 days. The duration of five nymphal instars was 3 - 4, 2 - 3, 3 - 4, 2 - 4 and 4 - 6 days, respectively. The longevity of male and female adults was 7 - 11 and 9 - 19 days, respectively.

The evaluation of duration in each stage of *W. rotunda* feeding on *T. palmi* larvae, *C. cephalonica* eggs and *Tetranychus* sp. adults, shown that egg incubation period was 5.50 $\pm$ 0.51, 5.85 $\pm$ 0.37 and 5.15 $\pm$ 0.37; the first nymphal stages was 2.20 $\pm$ 0.41, 3.00 $\pm$ 0.79 and 3.05 $\pm$ 1.19; the second nymphal stages was 2.26 $\pm$ 0.07, 2.75 $\pm$ 0.30 and 3.00 $\pm$ 1.41; the third nymphal stages was 2.00 $\pm$ 0.69, 2.72 $\pm$ 0.89 and 2.75 $\pm$ 1.12; the fourth nymphal stages was 2.94 $\pm$ 0.43, 2.53 $\pm$ 0.62 and 2.85 $\pm$ 0.93; the fifth nymphal stages was 4.76 $\pm$ 0.75, 5.00 $\pm$ 1.22 and 5.59 $\pm$ 2.21 days, respectively. The longevity of adults male was 10.13 $\pm$ 4.19, 4.88 $\pm$ 2.17 and 10.14 $\pm$ 7.40 and female was 16.67 $\pm$ 7.84, 5.00 $\pm$ 2.10 and 14.14 $\pm$ 7.76 days, respectively.

The evaluation of the biological life table revealed that the net reproductive rate of increase (R_o) of *W. rotunda* was 6.7067, 0, 0.1400 and 9.3533 when fed with *T. palmi* larvae, *M. hirsutus* crawlers, *C. cephalonica* eggs and *Tetranychus* sp. adults respectively. The net reproductive rate of increase (R_o) was highest when fed with *Tetranychus* sp. adults. The partial ecological life table also synchronized with these results, revealed that *W. rotunda* shown lowest mortality during the first nymphal instar when feeding on *T. palmi* larvae, *M. hirsutus* crawler and *Tetranychus* sp. adults and lowest mortality during the fifth nymphal instars when feeding on

C. cephalonica eggs but no progeny when feeding on *M. hirsutus* crawlers. It assumed to Rattanaka (2003) who reported that the net reproductive rate of increase (R_o) of *W. rotunda* was 6.6033, 12.4200 and 0, when fed with *T. palmi* , *Tetranychus* sp. and *A. gossypii*, respectively. The net reproductive rate of increase (R_o) was highest when fed with *Tetranychus* sp.

Results from the analysis of biological life table and duration period of *W. rotunda* feeding with *T. palmi* larvae, *C. cephalonica* eggs and *Tetranychus* sp. adults. Revealed that larvae of *T. palmi* and adults of *Tetranychus* sp. was suitable food source for mass rearing *W. rotunda*, *C. cephalonica* eggs and *M. hirsutus* crawlers was benefit for alternative prey for mass rearing of *W. rotunda* in laboratory. This study obtained in different result from JeongHwan *et al*., (1991), they supplied *A. gossypii* as prey for anthocorid predator, *Orius strigicallis*. They have good results for rearing this predator.

These demonstrated that each anthocorid predators have theirs suitable prey for development throughout the life spans. Mite and *T. palmi* were suitable preys for developing mass rearing of *W. rotunda* for augmentative biological control of *T. palmi* in Thailand.

The efficiency of *W. rotunda* when released adults of *W. rotunda* 1, 2, 3 and 4 for controlled 100 larvae of *T. palmi* in the cage. It indicated that numbers of *T. palmi* were exhausted in 5, 6, 8 and 9 days, respectively but in the control cage, the number of *T. palmi* were decreased in the fifth day and then increased in a short time. The results shown that releasing of *W. rotunda* in ratio of 4 : 100 (*W. rotunda* : *T. palmi*) for exhausted density of *T. palmi* within the fifth day. And another release ratio, there was successful to controlling of *T. palmi* within the ninth day. It assumed to Urano *et al*., (2003) who reported that when released 71 adults of *W. rotunda* were release ratio was 1 : 4 (adult bug : thrips) for prey density of 0.06 thrips per leaf. It was successful in controlling a *T. palmi* population that had such a low density at the release time.

The result from this study with rearing technique and efficiency study of *W. rotunda*, it should be utilized for biological control of *T. palmi* in Thailand.

CONCLUSION

The investigation on biology of *W. rotunda* when fed with *T. palmi* larvae, *C. cephalonica* eggs and *Tetranychus* sp. adults were investigated under laboratory condition (28 $\pm$ 2 ^{o}C and 75 $\pm$ 2 % RH). General morphology description was not different when fed with different species of preys. The egg was laid by insert singly in the upper or lower of eggplant leaves in the midrib of major veins. The individual was jug-shape and round oval. The newly laid eggs was creamy white and turned to red before hatching. The first nymphal instar was red in color and elongate-oval shaped, became immediately predator after emerged and invaded prey by using stylet piercing in the prey body. The second nymphal instar, the body color was become to dark red and quick. The third nymphal instar had the wing pad appeared from the mesothorax and it was obvious in the fourth and fifth nymphal instar, in these instar, the body was round-oval and more dark-red in color.

Duration stages of *W. rotunda* when fed with different species of prey was not different in nymphal stage but the duration stage of adult when fed with *T. palmi* larvae and *Tetranychu*s sp. adults higher than fed with *C. cephalonica* eggs.

The analysis of biological life table and partial partial ecological life table revealed important population attributed of *W. rotunda* from the construction of biological life table when fed with *T. palmi* larvaE, *C. cephalonica* egg and *Tetranychus* sp. adults analysis was: the net reproductive rate of increase (R_o) = 6.7067, 0.1400 and 9.353; the cohort generation time (T_c) = 29.6750, 25.8571 and 41.7819 days; the capacity for increase (r_c) = 0.0641, - 0.0760 and 0.0535; and the finite rate of increase (λ) = 1.0662, 0.9971 and 1.0550, respectively. When fed with *M. hirsutus* (Green) crawlers the net reproductive rate of increase (R_o) = 0. The results of partial partial ecological life table was investigated, *W. rotunda* could be survived until third and fifth nymphal instar when fed with *M. hirsutus* crawler and *C. cephalonica* egg, respectively.

The efficiency of *W. rotunda* when released adult of *W. rotunda* 1, 2, 3 and 4 for controlled 100 larvae of *T. palmi* in the cage. It indicated that numbers of *T.palmi* was exhausted in 5, 6, 8 and 9 days, respectively but in the control cage, the number of *T. palmi* was decreased in the fifth day and then it increased in a short time. Efficiency of 2, 3 and 4 adults of *W. rotunda* were not significant different, 1 and 2 adults of *W. rotunda* were not significant different for controlling 100 larvae of *T. palmi* but 1 adults of *W. rotunda* was different with 3 and 4 adults of *W. rotunda* for controlling 100 larvae of *T. palmi*.

The *T. palmi* larvae and *Tetranychus* sp. adults was suitable preys for mass rearing of *W. rotunda*. Although, when fed with *T. palmi* larvae net reproductive rate of increase (R_o) and the cohort generation time (T_c) was higher than fed with adults of *Tetranychus* sp. but the capacity for increase (r_c) and the finite rate of increase (λ) was nearly. And *Tetranychus* sp. adults could be easily to mass rearing.

The efficiency of *W. rotunda* appropriated when released 4 adults of *W. rotunda* in the ratio 4 : 100 (adult *W. rotunda* : *T. palmi*) as controlling *T. palmi* in five day. This ratio was successful to controlling *T. palmi* , when the population had a low density at the release time.

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