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Abstract

The current research aimed to study biological control of pest thrips *Frankliniella occidentalis* (PERGANDE) (Thys., Thripidae), *Thrips tabaci* LINDEMAN (Thys., Thripidae) and *Gynaikothrips ficorum* (MARCHAL) (Thys., Phlaeothripidae) using predatory bug species: *Geocoris ochropterus* FABR. (Het., Lygaeidae), *Montandoniola moraguesi* (PUTON) (Het., Anthocoridae), *Orius similis* ZHENG (Het., Anthocoridae) and *Scipinia subula* HSIAO et REN (Het., Reduviidae). Firstly, the biology and prey consumption of the four predatory bug species were experimented at temperature 25^{o}C. In further research, *G. ochropterus*, which displayed high prey consumption, fecundity and long longevity, was selected to study its biology and prey consumption at temperatures 18 and 30^{o}C. After that, its prey consumption in changing prey offer, the effect of extreme temperatures, its prey preference for prey ages and species, the effect of the different nutritions, as well as its cannibalism and the intraguild predation with *O. similis* were determined at temperature 25^{o}C. Finally, greenhouse experiments were conducted to confirm the efficiency of *G. ochropterus* for the biological control of the pest thrips.

Under laboratory conditions, the results showed that all the tested predators, except *S. subula*, were able to complete their life cycles with the three pest thrips species as prey at temperature 25^{o}C. Among them, *G. ochropterus* was the most superior in terms of prey consumption, fecundity and longevity. Further experiments revealed that *G. ochropterus* displayed shorter life cycle, lower mortality, higher fecundity and daily prey consumption at temperature 30^{o}C than at 18^{o}C. In addition, *G. ochropterus* showed the adaptability to changing prey offer. It also developed well with considerably high prey consumption at extremely high constant and changing temperatures (35 and 35/25^{o}C). Under extremely low temperature 3 and 6^{o}C, the adults of *G. ochropterus* showed high tolerance. Moreover, *G. ochropterus* could exhibit prey preference for certain life stages of thrips, and clearly preferred pest thrips to the non-thrips prey species. Different nutritions affected the development and survival period of *G. ochropterus*, with the adult predators living for a considerable period of time on 10% honey emulsion. Its cannibalism and intraguild predation with *O. similis* occurred in the experiments, and reduced with sufficient prey availability. Under greenhouse conditions, releasing a pair of *G. ochropterus* adults per plant caused up to 92.1, 85.7, and 83.7% reductions in the populations of *F. occidentalis*, *T. tabaci* and *G. ficorum*, respectively.

Biologische Kontrolle verschiedener Thripse Arten unter Verwendung räuberischer Prädatoren

Kurzfassung

Das Ziel der vorliegenden Arbeit ist die Untersuchung der biologischen Kontrolle der Thripse-Arten *Frankliniella occidentalis* (Pergande) (Thys., Thripidae), *Thrips tabaci* Lindeman (Thys., Thripidae) und *Gynaikothrips ficorum* (MARCHAL) (Thys., Phlaeothripidae) unter Verwendung räuberischer Käfer-Arten: *Geocoris ochropterus* FABR. (Het., Lygaeidae), *Montandoniola moraguesi* (PUTON) (Het., Anthocoridae), *Orius similis* Zheng (Het., Anthocoridae) und *Scipinia subula* Hsiao et REN (Het., Reduviidae). Zuerst wurde die Biologie und das Fraßverhalten der vier prädatorischen Käfer-Arten bei 25°C untersucht. Für Weiterführende Untersuchungen zur Biologie und zum Fraßverhalten bei 18 und 30°C wurden mit *G. ochropterus,* welcher einen hohen Beuteverbrauch, eine hohe Fertilität und eine lange Vitalität aufweist durchgeführt. Der Beuteverbrauch bei unterschiedlichem Beuteangebot, Preferencen für Beute bestimmter Arten und bestimmten Alters, der Einfluss extremer Temperaturen, der Einfluss unterschiedlicher Ernährung sowie die Bedeutung von Kannibalismus und Interaktionen zwischen den Beutearten wurden bei 25°C untersucht. Abschließend wurden Gewächshausversuche zur Untersuchung der Eignung der ausgewählten Prädatoren für eine biologische Kontrolle von Thrips-Arten durchgeführt.

Die Laboruntersuchungen zeigten, dass alle getesteten Prädatoren außer *S. subula* in der Lage waren ihren Lebenszyklus mit den drei Thrips-Arten als Beute zu vollenden. Hinsichtlich Beuteverzehr, Fertilität und Vitalität war *G. ochropterus* unter den Prädatoren überlegen. Als günstige Temperatur erwies sich 30°C gegenüber 18°C. Zusätzlich zeigt *G. ochropterus* eine Anpassung an wechselndes Beuteangebot. Eine gute Entwicklung konnte auch bei extrem hohen Beutevorkommen und extrem hohen konstanten Temperaturen (35°C) oder wechselnden (35/25°C) Temperaturen vermerkt werden. Adulte *G. ochropterus* Species zeigten eine hohe Toleranz gegenüber niedrigen Temperaturen von 3 und 6°C. Des Weiteren wies *G. ochropterus* eine Präferenz für Thripse in einem bestimmten Entwicklungsstadium auf und bevorzugte schädliche Thrips-Arten deutlich gegenüber anderen Beuteinsekten. Unterschiedliche Ernährung beeinflusste die Entwicklung und die Lebensdauer von *G. ochropterus*. Es ist möglich adulte Prädatoren eine für einen längeren Zeitraum auf 10% Honigemulsion zu züchten. Kannibalisums und zwischenartige Prädation mit *O. similis* konnte in den Versuchen beobachtet werden, eine ausreichende Verfügbarkeit der Beute wirkt diesem jedoch entgegen. Unter Gewächshausbedingungen, konnten bei einem *G. ochropterus* Paar pro Pflanze Reduzierungen der *F. occidentalis*, *T. Tabaci* und *G. ficorum* Populationen von jeweils 92.1, 85.7 und 83.7% erreicht werden.

CONTENTS

1 INTRODUCTION

Phytophagous thrips (Insecta: Thysanoptera) are able to establish populations in a variety of plant formations, and many of their species are economically important as pests in agriculture, horticulture and forestry (ANANTHAKRISHNAN 1993). Among these pest thrips, the western flower thrips, *Frankliniella occidentalis* (PERGANDE) and the onion thrips, *Thrips tabaci* LINDEMAN (Thys., Thripidae) have become major serious pests on a wide range of vegetables and ornamentals in fields and greenhouses throughout the world (TOMMASINI and MAINI 1995, MURAI 2000). They cause damage directly through destructively feeding and indirectly through transmitting lethal plant viruses (MARCHOUX et al. 1991, DEANGELIS et al. 1994). Cuban laurel thrips, *Gynaikothrips ficorum* (MARCHAL) (Thys., Phlaeothripidae) is another important pest thrips in a kind of popular ornamentals, banyan trees *Ficus* spp. and occasionally in orchids (HANLON and PAINE 2003). These pest thrips are difficult to control with insecticides because of their short life cycle, high reproduction, small size with cryptic habits and their ability to develop high-level insecticide resistance (ZHAO et al. 1994). In addition, the side effect of pesticides on environment and human being is a growing concern. Therefore, as an attempt to protect plants as well as to reduce the application of pesticides, it is valuable to develop biological control methods for the management of the pest thrips.

Predatory bugs may be a good source of natural enemies for biological control of pest thrips. Some studies have revealed that certain predatory bugs can be used to control small and hidden arthropod pests (BLAESER et al. 2004). For example, *Dicyphus tamaninii* WAGNER (Het., Miridae) was proved to be a successful predatory bug against *Aphis gossypii* GLOVER (Hom., Aphididae) (SALEH 2002, SENGONCA and SALEH 2002). The predatory bug *Macrolophus pygmaeus* (RAMBUR) (Het., Miridae) showed efficient predation against some aphids, whiteflies and mites (PERDIKIS and LYKOURESSIS et al. 2000, LYKOURESSIS et al. 2001). To develop biological control of pest thrips, some studies have been conducted on different predatory bugs, i.e., *D. tamaninii*, *M. pygmaeus* and several *Orius* species (Het., Anthocoridae) (SMITLEY 1992, BRAMAN and BESHEAR 1994, DISSEVELT et al. 1995, GABARRA et al. 1995, CASTAÑÉ et al. 1996, DELIGEORGIDIS 2002, SANCHEZ and LACASA 2002, SENGONCA and SALEH 2002, BLAESER et al.

2004). Most of these predatory species showed good results in the studies. However, the predation efficiency varied much according to predatory species. Moreover, some of the tested species were not promising biological control agents against the pest thrips. Further investigations are necessary to find more predatory bug species in order to enrich the biological control agents and develop more options for biological control of pest thrips.

Predatory bugs *Geocoris ochropterus* FABR. (Het., Lygaeidae) (KUMAR and ANANTHAKRISHNAN 1985, MIAO et al. 2003), *Montandoniola moraguesi* (PUTON) (Het., Anthocoridae) (DOBBS and BOYD 2006), *Orius similis* ZHENG (Het., Anthocoridae) (ZHANG et al. 1994, ZHOU and LEI 2002), and *Scipinia subula* HSIAO et REN (Het., Reduviidae) (HUANG et al. 2007, RUAN et al. 2008) were reported abundant in fields of some regions. *G. ochropterus* can predate thrips, mites, aphid and white flies (KUMAR and ANANTHAKRISHNAN 1985). *M. moraguesi* is an effective biological control agent against *G. ficorum* and has been introduced into Hawaii and Bermuda to suppress the thrips population (DOBBS and BOYD 2006). *O. similis* has been studied as a predator against the thrips *Frankliniella formosae* MOULTON (Thy., Thripidae), eggs and hatched larvae of pink bollworm, *Pectinophora gossypiella* (SAUNDERS) (Lep., Gelechiidae), as well as different aphid species (ZONG et al. 1987, ZHANG et al. 1994, ZHOU and LEI 2002, SENGONCA et al. 2008). *S. subula* of certain life stages were also found to predate aphids, whiteflies and thrips (RUAN et al. 2008). However, no profound research has been conducted on the four predatory bug species as biological control agents against thrips. So far, very little knowledge is known about them.

To evaluate the potential of a predator for a biological control program, it is very important to obtain the knowledge about its biology and prey consumption at different temperatures. If the natural enemy is a polyphagous predator, which means it feeds on not only different insect species but also non-insect nutrition, it is also important to study the predator's prey preference, the effect of different nutrition, and its cannibalism and intraguild predation with another natural enemy. This is true especially when it is taken into account that in the agro-ecosystem, several pest species naturally exist together and might serve as potential prey for the predator and also there are other natural enemies that can interact with it. In agro-ecosystem, the sap of the host leaves sometimes also serves as an alternative nutritional source for the predator and affects its

development and survival. At last, releasing of a natural enemy under more natural conditions is necessary to estimate its efficiency in controlling a given pest species.

Therefore, the present work aimed to comparatively study the biology and prey consumption of the four predatory bug species *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* with the pest thrips *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey in the laboratory. After that, the best suitable predatory bug for each thrips was selected for further research. Firstly, the selected predator *G. ochropterus* was observed in terms of its biology and prey consumption at different temperatures. The prey consumption in changing prey offer was also observed. In addition, the effects of extremely high constant and changing temperatures on the development and prey consumption of *G. ochropterus*, as well as the effect of extremely low temperature on the predator's survival was experimented. Moreover, the prey-age and prey-species preferences of *G. ochropterus*, as well as the effect of different nutritions were investigated. The cannibalism of *G. ochropterus*, and the intraguild predation between it and *O. similis* were also tested with prey absent and present. Finally, greenhouse experiments were carried out to confirm the efficiency of *G. ochropterus* for the biological control of *F. occidentalis, T. tabaci* on sweet pepper plants and *G. ficorum* on banyan trees.

2 MATERIALS AND METHODS

2.1 Laboratory experiments

2.1.1 Rearing of the insects

2.1.1.1 Rearing of the pest insects

2.1.1.1.1 *Frankliniella occidentalis*

The stock culture of *F. occidentalis* was established on bean plants (*Phaseolus vulgaris* L., cv Marona) with individuals obtained from the original stock culture at Institute of Crop Science and Resource Conservation, University of Bonn. The rearing was carried out in a climatically controlled room at 25±1°C temperature, 60±10% RH and 16:8 h (L:D) photoperiod with an artificial light intensity of about 4000 Lux. Bean plants were usually planted in trays (60×40 cm) under greenhouse conditions before transferring to the climate room. The fresh bean plants were used to replace the heavily infested ones weekly.

To obtain desired life stages of *F. occidentalis* for different experiments, a kind of cage, "Rearing Cage", for breeding thrips or other insects in incubators had been developed from round Plexiglas cages with 11 cm in diameter and 3 cm in height (Fig. 1).

Fig. 1: Rearing Cages using for the obtaining of the appropriate stages of insects for experiments

The cages were filled with 0.5 cm thick agar gel layer to keep the leaves fresh, and had three meshed holes in the lid for aeration. To prepare appropriate age of *F. occidentalis*, freshly bean leaves were placed upside down onto the agar gel layer in the cages, and 20-30 adult females of *F. occidentalis* for each cage were picked up from stock culture and transferred into the cages for egg laying. After 24 h, the adult females were removed to the newly prepared cages to obtain eggs again. The eggs obtained in the cages were kept in an incubator at the above-mentioned climatic conditions for development until the thrips reached the life stage desired for the experiments.

2.1.1.1.2 *Thrips tabaci*

The stock culture of *T. tabaci* was established on leek plants (*Allium porrum* L.) in a climatically controlled room at the above-mentioned temperature, humidity and photoperiod with the same artificial light intensity. The stock culture started with female adults of *T. tabaci* obtained from the original stock culture at Institute of Crop Science and Resource Conservation, University of Bonn. Leek plants were usually planted in pots (11 cm in diameter and 11 cm in height) under greenhouse conditions before transferring to climate room. The fresh leek plants were used to replace the heavily infested ones weekly.

To obtain the desired life stages of *T. tabaci*, the same procedure as for *F. occidentalis* was used, except that the thrips species was replaced with *T. tabaci* and the bean leaves were replaced with leek leaves.

2.1.1.1.3 *Gynaikothrips ficorum*

Population of *G. ficorum* was maintained on young banyan trees (*Ficus microcarpa* L.) in a climatically controlled room at the above-mentioned temperature, humidity and photoperiod with the same artificial light intensity (Fig. 2). The individual for the stock culture of *G. ficorum* were collected from the banyan trees in Fuzhou City of southern China. Stems with diameter of 0.3-0.5 cm were also detached from the banyan trees in Fuzhou City, and cut into 20 cm long. The prepared stems were cultured by the method of cuttage in pots (12 cm in diameter and 12 cm in high), in order to obtain little young banyan trees. Fresh banyan trees in pots were transferred to the room in order to replace the heavily infested ones.

For obtaining the desired life stages of *G. ficorum*, young banyan trees were exposed to *G. ficorum* infestation in the stock culture. After 24 h, the adults were removed from the trees. The laid eggs were used directly or reared further in meshed cages (80×50×60 cm) at above-mentioned climatic condition, and checked daily till they reached the required ages.

Fig. 2: Rearing *Gynaikothrips ficorum* on young banyan trees (*Ficus microcarpa*) in pots

2.1.1.1.4 Other prey insects

The rearing of other pest insects as prey, like *Aphis fabae* SCOPOLI (Hom., Aphididae) on broad bean plants, *Aphis gossypii* GLOVER (Hom., Aphididae) on cotton plants, *Bemisia tabaci* (GENN.) (Hom., Aleyrodidae) on cucumber plants and *Tetranychus urticae* KOCH (Acari, Tetranychidae) on bean plants, were maintained exclusively in meshed cages (80×50×60 cm). The rearing of these four pest species were started with the individual obtained from original stock cultures at Institute of Crop Science and Resource Conservation, University of Bonn. All the plants were usually planted in pots under greenhouse conditions. All the rearing of these pest species were took place at 25±1°C temperature, 60±10% RH and 16:8 (L:D) photoperiod with an artificial light intensity of about 4000 Lux.

A. fabae was used as prey to establish or obtain the stock culture and uniformly aged individuals of *S. subula*. Mixed population of *A. fabae* with the infested host plant leaves were picked up from its stock culture, and offered as prey for *S. subula*.

One or two-day-old nymphs of *A. gossypii* for experiments were prepared by transferring the adult aphids onto cucumber leaves in Rearing Cages mentioned in Fig. 1. After 24 h, the adult aphids were removed, and the nymph aphids were used directly or reared further for one day.

Pupae of *B. tabaci* for experiments were prepared by exposing the cucumber plants to *B. tabaci* infestation in the stock culture for 24 h, and then *B. tabaci* adults were removed. The plants with the eggs were fostered under the same climatic conditions as used for the stock culture. The development of the eggs was checked daily until the individuals reached the pupa stage. The cucumber leaves containing the pupae were excised into leaf discs which would be used in experiment. *B. tabaci* on the leaf discs were removed until 20 pupae per leaf disc were remained.

To obtain the adult females of *T. urticae* for experiments, its mixed population as well as the infested bean leaves were picked up from its stock culture, and were identified under a binocular microscope. Adult females were collected gently by using a camel-hair brush.

2.1.1.2 Rearing of the predatory insects

2.1.1.2.1 *Geocoris ochropterus*

G. ochropterus was collected from the soybean plantation in Fuzhou City of southern China (Fig. 3). The stock culture of *G. ochropterus* was maintained on cotton or pepper plants with *F. occidentalis* or *T. tabaci* as prey in the meshed cages (80×50×60 cm). The climatic condition for the rearing was 25±1^{o}C temperature, 60±10% RH and 16:8 h (L:D) photoperiod with an artificial light intensity of about 4000 Lux.

Fig. 3: Eggs, N_1 nymph and adult of predatory bug *Geocoris ochropterus*

Desired stages of *G. ochropterus* for different experiments were obtained from the Rearing Cage as described in Fig. 1. Every 5 adult females and 2 adult males of the predator were transferred onto pepper or cotton leaves in each Rearing Cage. Individuals of different life stages from *F. occidentalis*, *T. tabaci* or *G. ficorum* were offered into the cages as prey. After 24 h, the adults of *G. ochropterus* were moved to new cages to lay eggs again. The eggs laid in 24 h were reared with mixed population of the desired thrips species as prey on the host plant leaves in the Rearing Cages. The Rearing Cages with the eggs were placed in an incubator at the same climatic condition as used for the stock culture. The development of the eggs was checked daily until they reached the life stages required in experiments.

2.1.1.2.2 *Montandoniola moraguesi*

M. moraguesi was collected from the banyan trees (*F. microcarpa*) in Fuzhou City of southern China (Fig. 4). Its stock culture and uniformly aged individuals for experiments were conducted in the same procedure as for *G. ochropterus* in capital 2.1.1.2.1. The climatic condition for the rearing was the same as mentioned above.

Fig. 4: Eggs, N_1 nymph and adult of predatory bug *Montandoniola moraguesi*

2.1.1.2.3 *Orius similis*

O. similis was obtained from the cucumber plantation in Fuzhou City of southern China (Fig. 5). The stock culture and desired stages of *O. similis* were established or obtained by the same procedure used for *G. ochropterus* in capital 2.1.1.2.1. The climatic condition for the rearing was the same as described above.

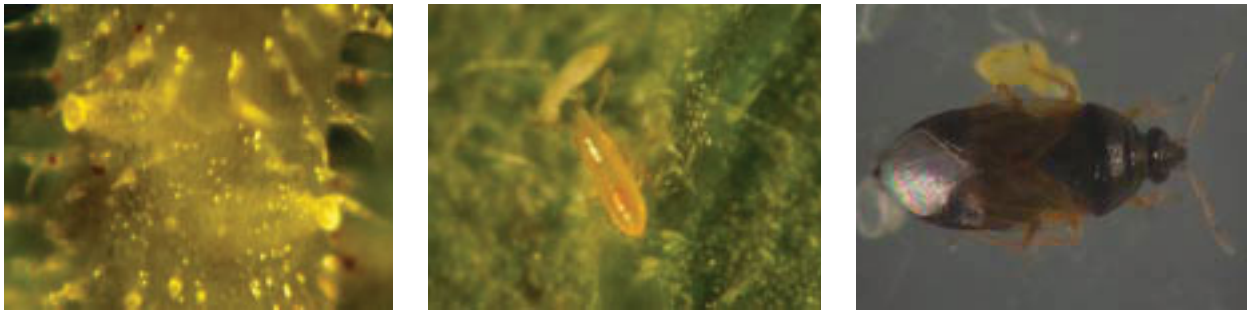

Fig. 5: Eggs, N_1 mymph and adult of predatory bug *Orius similis*

2.1.1.2.4 *Scipinia subula*

S. subula was collected from the plantation of Garden Balsam (*Impatiens balsamina* L.) in Fuzhou City of southern China (Fig. 6). The stock culture of *S. subula* was maintained in meshed cages (80×50×60 cm) with *A. fabae* as prey on broad bean plants, or with *A. gossypii* as prey on pepper plants. The climatic condition for the rearing was the same as mentioned before.

Desired stages of *S. subula* for experiments were obtained from the Rearing Cages as described in Fig. 1. Every 5 adult females and 2 adult males of the predator were picked from the stock culture, and then transferred into each cage, which previously contained broad bean leaves infested with *A. fabae*. After 24 h, the adults were moved to new cages to lay eggs again. The laid eggs were used directly or reared with aphid as prey for a certain period of time in an incubator. The rearing of the eggs were daily checked until they reached the uniformly life stages required in experiments. The incubator was at the same climatic condition used for its stock culture.

Fig. 6: Eggs, N1 nymph and adults of predatory bug *Scipinia subula*

2.1.2 Biology and prey consumption of *Geocoris ochropterus*, *Montandoniola moraguesi* , *Orius similis* and *Scipinia subula* at temperature 25°C

2.1.2.1 With *Frankliniella occidentalis* as prey

The biology and prey consumption of *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* were studied in the laboratory at 25±1°C temperature, 60±10% RH and 16:8 h (L:D) photoperiod. Experiments on embryonic and nymphal development, mortality, longevity, fecundity as well as the prey consumption were carried out in a kind of arenas (Fig. 7), which were developed from the round Plexiglas cages with 3.6 cm in diameter and 1.5 cm in height. The cages were filled with 0.3 cm thick agar gel layer and had a meshed hole in the lid to allow aeration. Sex ratio, on the other hand, was carried out in the Rearing Cages mentioned in Fig. 1.

Fig. 7: Arenas for the experiments biology and prey consumption

To determine the developmental period of embryonic stage of the four predatory bug species, the adult females and males of *G. ochropterus*, *M. moraguesi* and *O. similis*, which were reared from N_1 instar to adult with mixed population of *F. occidentalis* as prey, were confined to lay eggs in the Rearing Cages as described in Fig. 1, with 5 females and 2 males from the same predatory species in a Rearing Cage. Mixed population of *F. occidentalis* was offered as prey. The adults were moved away after 24 h, and the laid eggs were collected for the experiment. To obtain the eggs of *S. subula*, every 5 adult females and 2 adult males were picked up from its stock culture, and transferred onto broad been leaves in each Rearing Cage as described in Fig. 1. Mixed population of *A. fabae* was offered as prey. After 24 h, the adults were moved away and the eggs

were used in the experiment. The eggs of *G. ochropterus* and *S. subula* were laid on the leaf surface. They were counted directly, and transferred onto the leaf discs in the arenas as described above for embryonic development at the desired temperature. The eggs of *M. moraguesi* and *O. similis* were inserted into the host leaf tissue, and could be counted under a binocular microscope by observing the egg operculum. After counting, the eggs of *M. moraguesi* and *O. similis* were transferred with the host leaves to the arenas and were kept in an incubator with the desired temperature. They were daily checked to record the period of embryonic development for each predatory bug species until the eggs hatched. The experiments were replicated at least 20 times for each predatory species.

To determine the period of nymphal development of the four predatory bug species, the newly hatched N_1 nymphs of each predatory species were singly transferred using a camel hairbrush into arenas, which previously contained cucumber leaf discs for *M. moraguesi*, or bean leaf discs for the other predatory species. The second instar larvae (L_2) of *F. occidentalis* were daily offered as prey in an excess number (20, 30 and 40 per arena for N_1-N_2, N_3 and N_4-N_5 predatory nymphs, respectively). The arenas were kept in an incubator with the desired temperature, and checked daily for the skins of moulted nymphs until adult emergence. During the experiment, the predatory nymphs were daily transferred to the new similar arenas with fresh prey offer. The experiments were replicated 20 times for each predatory bug species.

During the developmental period experiment, the mortality of each predatory species as well as the number of consumed thrips was recorded daily. Thrips, which were consumed by the predator, were empty of fluid and easily distinguished from those of natural mortality.

To establish the sex ratio of each predatory bug species, 200 eggs from each species were developed to adult with mixed population of *F. occidentalis* as prey on cucumber leaves in the Rearing Cages. The emerged adults were sexed under a binocular microscope. Percentage of females and males were calculated for each predatory bug species.

To observe longevity and fecundity, newly emerged adults of each predatory bug species were transferred to the arenas, with one female and male from same species in an arena. Mixed

population of *F. occidentalis* was offered as prey on cucumber leaf discs in the arenas. The adults in the experiment were daily transferred to new arenas with new prey offer. The laid eggs in the old arenas were counted under binocular microscope. The old arenas were also checked to record the longevity of both sexes after the individuals died. Ten replicates were set for the experiment of each predatory bug species.

The prey consumption by the nymphs and adults of the four predatory species were determined throughout the nymphal development and the first 15 days after adult emergence. To obtain the prey consumption by the nymphs, the number of consumed thrips was daily recorded during the above-mentioned experiment on the nymphal development of the four predatory species. The consumed thrips were empty of fluid, and easily distinguished from those of natural mortality. To determine prey consumption by the adults, freshly emerged adults of each predatory bug species were singly kept on cucumber leaf discs in the arenas. L_2 larvae of *F. occidentalis* were daily offered as prey in an excess number (40 per arena). The females accessed to males for the first time on the 2nd day after emergence and then once weekly. During the experiment, the adults were daily transferred to new arenas with fresh prey offer. The number of *F. occidentalis* consumed by each predatory individual was daily recorded. The experiments were conducted from 1st to 15th day after adult emergence. Fifteen replicates were used with each sex of each predatory bug species.

2.1.2.2 With *Thrips tabaci* as prey

Experiments on biology and prey consumption of *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* with *T. tabaci* as prey on cucumber leaves were conducted in the laboratory at 25±1^{o}C temperature, 60±10% RH and 16:8 h (L:D) photoperiod. The experiments were carried out in the same procedure as described in capital 2.1.2.1, except that the host plant leaves were all replaced with cucumber leaves, and the thrips species was replaced with *T. tabaci*. In the experiments on nymphal development and prey consumption of the four predatory species, L_2 larvae of *T. tabaci* were daily offered as prey with numbers of 20, 30 and 40 per arena for N_1-N_2, N_3 and N_4-adult of the predators, respectively. The experiments were replicated in the same way as described in capital 2.1.2.1.

2.1.2.3 With *Gynaikothrips ficorum* as prey

The embryonic and nymphal development period, mortality, sex ratio, longevity, fecundity as well as prey consumption of *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* were determined with *G. ficorum* as prey on leaves of *F. microcarpa*. All these determinations were conducted in the same procedure as described in capital 2.1.2.1, except that host leaf and thrips species were changed to *F. microcarpa* leaf and *G. ficorum*, respectively. For observing the nymphal development and prey consumption of the predators, L_2 larvae of *G. ficorum* were daily offered as prey in numbers of 10, 20 and 30 per arena for predatory N_1-N_2, N_3 and N_4-adult, respectively. The experiments on Biology and prey consumption of the four predatory bug species were also replicated in the same way as described in capital 2.1.2.1.

2.1.3 Biology of the selected predator *Geocoris ochropterus* at temperature 18 and 30°C

Based on the results of the investigation on biology and prey consumption of *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* with *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey, *G. ochropterus* was selected for further research.

Biology of *G. ochropterus* was studied by feeding on each of the three thrips species as prey at temperatures 18 and 30±1°C, with other climatic condition as 60±10% RH and 16:8 h (L:D) photoperiod. In the study, embryonic and nymphal development, mortality, longevity, fecundity were experimented in the arenas as described in Fig. 7. The sex ratio was determined in the Rearing Cages mentioned in Fig. 1.

2.1.3.1 With *Frankliniella occidentalis* as prey

To determinate the embryonic developmental period at temperatures 18 and 30±1°C, the eggs freshly laid in 24 h by adult females of *G. ochropterus*, which grew up from their N_1 instars with *F. occidentalis* as prey in the Rearing Cages, were transferred onto cucumber leaf discs in the arenas. The arenas with the eggs were placed in incubators at the two temperatures. The eggs were daily checked to record the period of embryonic development until they hatched. For each temperature, 20 eggs were tested.

Developmental periods of the nymphal instars of *G. ochropterus* were determined by feeding its freshly hatched nymphs on L_1 and L_2 larvae of *F. occidentalis* as prey at temperature 18 and 30°C. The experiments were carried out on cucumber leaf discs in the arenas. The predatory nymphs were singly kept in arenas. For the nymphs developing at 18°C, *F. occidentalis* was daily offered as prey in the number of 30 L_1 or 20 L_2 larvae per arena. For the nymphs at 30°C, the numbers of L_1 larvae offered as prey were 40-50, 80-90 and 150-160 per arena for N_1-N_2, N_3-N_4 and N_5 predator instars, respectively. While L_2 larval thrips were daily offered as prey in the number of 30, 40 and 60 per arena for N_1-N_2, N_3-N_4 and N_5 predator instars, respectively. New similar arenas with fresh prey offer were daily prepared to replace the old ones. The old arenas were daily checked for the skins of moulted nymphs. Twenty replicates were set for each prey age at each temperature.

During the developmental period experiment, the mortality of nymphal *G. ochropterus* was recorded daily for both experiment temperatures.

To obtain the sex ratio of *G. ochropterus* at the 18 and 30°C temperatures, the experiment was started with 20 pairs of freshly emerged adult females and males of *G. ochropterus*. Every five pairs of the adults were confined in one Rearing Cage to lay eggs at temperature 25±1°C. Mixed population of *F. occidentalis*, including more than 300 individuals with life stages between L_2 instar and adult, was daily offered as prey. The adult females and males were daily transferred to new cages with fresh prey offer. The eggs produced by the adult females during the 3rd, 6th and 9th week after emergence were daily collected and divided into two groups to rear at 18 and 30°C temperatures. The eggs were reared also in the similar Rearing Cages with mixed population of *F. occidentalis* as prey on cucumber leaves. Percentage of males and females of *G. ochropterus* developed from the eggs produced in the same week was calculated for each temperature.

Longevity of *G. ochropterus* was determined in an experiment of prey consumption by the adult predators. Freshly emerged adult females and males of *G. ochropterus* were kept singly on cucumber leaf discs in the arenas. For determing the longevity at 18°C temperature, L_1 or L_2

larvae of *F. occidentalis* were daily offered as prey in the number of 30 or 20 per arena, respectively. While at 30°C, the offered number of prey individuals in an arena was 150-160 L_1 or 60 L_2 larvae. The females had accessed to males for the first time on the 2nd day after their emergence and then once weekly. During the experiments, the predatory adults were daily transferred into new similar arenas with fresh prey offer. The death of the predators was daily monitored until all predators died in the experiment. There were 12 replicates of experiments with each predator sex and prey stage at each temperature.

To establish fecundity of *G. ochropterus* at the two temperatures, newly emerged adults were transferred to the arenas, with a pair of female and male in an arena. Mixed population of *F. occidentalis* was offered on cucumber leaf discs in the arenas as prey. The adults in the experiment were daily transferred to new arenas with new prey offer. The eggs laid by the adult females in the old arenas were counted under binocular microscope. The death of the adults was also recorded. The experiments were replicated 10 times at each temperature.

2.1.3.2 With *Thrips tabaci* as prey

Biology of *G. ochropterus* with *T. tabaci* on cucumber leaf at 18 and 30±1°C temperatures were investigated in the same procedures as used in capital 2.1.3.1, except that the thrips species was replaced with *T. tabaci*. The number of prey individuals and experiment replicates were also set in the same way as described in capital 2.1.3.1.

2.1.3.3 With *Gynaikothrips ficorum* as prey

Biology of *G. ochropterus* with *G. ficorum* as prey at 18 and 30±1°C temperatures were studied in the same procedures as used in capital 2.1.3.1, except that the thrips species was replaced with *G. ficorum* and cucumber leaf was replaced with leaf of banyan tree. In the experiments on nymphal development, mortality and longevity of *G. ochropterus*, L_1 and L_2 larvae of *G. ficorum* were daily offered as prey in the numbers of 30 and 20 per arena at 18°C, respectively. For these experiments at 30°C, the daily offered number of L_1 larvae as prey was 30, 40 and 60 per arena for N_1-N_2, N_3-N_4 and N_5-adult of *G. ochropterus*, respectively. The number of L_2 larvae was 20, 30 and 40 per arena for N_1-N_2, N_3-N_4 and N_5-adult of *G. ochropterus*, respectively. All

experiments on biology of *G. ochropterus* were replicated in the same way as described in capital 2.1.3.1.

2.1.4 Prey consumption by *Geocoris ochropterus* at temperature 18 and 30°C

Prey consumption by *G. ochropterus* were tested by feeding on L_1 and L_2 larvae of the three thrips species at 18 and 30±1°C, with other climatic condition as 60±10% RH and 16:8 h (L:D) photoperiod.

2.1.4.1 With *Frankliniella occidentalis* as prey

Prey consumption by the nymphal instars of *G. ochropterus* was investigated on cucumber leaf discs prepared in the arenas as described in Fig. 7. The N_1 nymphs of *G. ochropterus*, which freshly hatched from eggs, were singly confined in the arenas. For the experiment at temperature 18°C, *F. occidentalis* was daily offered as prey with the number of 30 L_1 or 20 L_2 larvae per arena. At 30°C, the offered number of L_1 larvae as prey was 40-50, 80-90 and 150-160 per arena for N_1-N_2, N_3-N_4 and N_5 instars, respectively. While L_2 larvae were daily offered as prey in the numbers of 30, 40 and 60 per arena for N_1-N_2, N_3-N_4 and N_5 instars, respectively. During the experiments, *G. ochropterus* nymphs were transferred to new arenas with fresh preys till they developed into adults. The number of consumed thrips in the old arenas was recorded. The experiments were replicated 20 times for each prey stage at each temperature.

Prey consumption by adults of *G. ochropterus* was also carried out in arenas mentioned in Fig. 7. Freshly emerged female and male adults of *G. ochropterus* were kept singly on cucumber leaf discs in the arenas. For the prey consumption at 18°C temperature, L_1 or L_2 larvae of *F. occidentalis* were daily offered as prey in the numbers of 30 or 20 per arena. At 30°C, the offered number of L_1 or L_2 larvae in an arena was 150-160 or 60, respectively. The females had accessed to males for the first time on the 2nd day after their emergence and then once weekly. During the experiments, the predatory adults were daily transferred into new similar arenas with fresh prey offer. The number of consumed thrips was recorded until the death of the last predatory bug in the experiment. There were 12 replicates with each predator sex and prey stage at each temperature.

2.1.4.2 With *Thrips tabaci* as prey

Prey consumption by the nymphal instars of *G. ochropterus* with L_1 and L_2 larvae of *T. tabaci* as prey on cucumber leaves was determined in the same procedure used in capital 2.1.4.1, where the prey consumption by the nymphal *G. ochropterus* with *F. occidentalis* as prey was investigated. Obviously, the thrips species was replaced with *T. tabaci* here. The offered number of L_1 and L_2 larval *T. tabaci* as prey was set in the same way as described in capital 2.1.4.1. All experiments here were also replicated in the same way as described in capital 2.1.4.1.

To observe the prey consumption by adult females and males of *G. ochropterus* with *T. tabaci* as prey, the procedure in capital 2.1.4.1, which was used to determine the prey consumption by adult *G. ochropterus* with *F. occidentalis* as prey, was modified by replacing the thrips species with *T. tabaci* and employed here. L_1 and L_2 *T. tabaci* were daily offered as prey in the same number as described for in capital 2.1.4.1. The replications for each experiment were also set in the same number as in capital 2.1.4.1.

2.1.4.3 With *Gynaikothrips ficorum* as prey

To obtain the prey consumption by nymphal *G. ochropterus* during development with *G. ficorum* as prey, the method in capital 2.1.4.1, where prey consumption by the predatory nymphs with *F. occidentalis* as prey was determined, was modified by replacing the thrips species on cucumber leaf discs with *G. ficorum* as prey on leaf discs of *F. microcarpa*. In the experiments at 18^{o}C temperature, *F. microcarpa* were daily offered as prey with a number of 30 L_1 or 20 L_2 larvae per arena. In the experiments at 30^{o}C, the offered number of the L_1 larvae in each arena was 30, 40 and 60 for N_1-N_2, N_3-N_4 and N_5 instars of *G. ochropterus*, respectively. While the offered number of the L_2 larvae was 20, 30 and 40 for N_1-N_2, N_3-N_4 and N_5 instars, respectively. There were 20 replicates for each prey stage at each temperature in the experiments.

To investigate the prey consumption by the adults of *G. ochropterus*, the procedure in capital 2.1.4.1, where the prey consumption by the adult predators was determined with L_1 and L_2 larvae of *F. occidentalis* as prey, was modified by replacing with *G. ficorum* on leaf discs of *F. microcarpa*. For determining the prey consumption at 18^{o}C temperature, 30 L_1 or 20 L_2 larvae of

G. ficorum were daily offered as prey in each arena. While at 30°C, the offered number of L_1 or L_2 larvae as prey was 60 or 40, respectively. For each predator sex with each prey stage at each temperature, the experiments were replicated 12 times.

2.1.5 Prey consumption by *Geocoris ochropterus* in changing prey offer

Prey consumption by *G. ochropterus* was studied with a changing number of L_2 larvae of *F. occidentalis* and *T. tabaci* as prey on cucumber leaf discs, as well as with *G. ficorum* as prey on leaf discs of banyan tree at temperature 25±1°C, relative humidity of 60±10% and a photoperiod of 16:8 h (L:D).

Seven-day-old adult females of *G. ochropterus* were tested over a period of 3 weeks. Each female predator was placed singly in the arenas as described in Fig. 7. During the 1st experimental week, 50, 20, 10 or 5 L_2 thrips from the same species were separately offered as prey in an arena. In the 2nd week of the experiment, the daily prey offer was all changed to 30 thrips per arena. During the 3rd experimental week, the prey number was switched again to 50, 20, 10 or 5 thrips/day for each arena. The female predators were transferred daily to new arena, which contained the appropriate number of each prey species. The number of consumed prey in the old cages was counted. The experiments were replicated ten times for each thrips species.

2.1.6 Effect of extremely high constant and changing temperatures on development and prey consumption of *Geocoris ochropterus*

Experiments were conducted to test the effect of a extremely high constant temperature 35±1°C and a changing temperature 35/25±1°C (L:D) on *G. ochropterus* during its immature developemt. In the experiments, the embryonic and nymphal developmental periods, mortality and prey consumption of *G. ochropterus* were observed by feeding on L_2 larvae of *F. occidentalis* and *T. tabaci* as prey on cucumber leaf discs. The predatory nymphs were also observed with *G. ficorum* as prey on leaf discs of *F. mirocarpa*. All these experiments were conducted in climatically controlled incubators with an artificial photoperiod of 16:8 h (L:D).

To determine the embryonic developmental period, eggs freshly laid in 24 h by *G. ochropterus* were transferred in mass onto cucumber leaves in the arenas (Fig. 7). The arenas with the eggs

were placed in incubators at the two temperatures. For each temperature, 20 eggs were tested. The eggs were daily checked to record the period of embryonic development till nymphs hatched from the eggs.

To observe the developmental periods of the nymphal instars of *G. ochropterus*, freshly hatched nymphs of *G. ochropterus* were singly introduced into the arenas. L_2 thrips larvae from same species were offered as prey. Afterward, the arenas were kept in incubators at the desired temperature. The predatory nymphs were daily transferred into new similar arenas with fresh prey offer until adult emergence. The old arenas were daily checked for the skins of moulted nymphs, mortality and the number of consumed thrips. The thrip larvae as prey were daily offered in numbers of 30, 40 and 60 per arena for N_1-N_2, N_3-N_4 and N_5 instars of *G. ochropterus*, respectively. The experiments at each temperature were set with 20 replicates.

2.1.7 Effect of extremely low temperatures on survival of *Geocoris ochropterus* in different life stages

The characteristics of high tolerance to extremely low temperature is helpful for a predator to build a sustainable population in field. Here, the mortality of *G. ochropterus* was determined under temperatures 3 and 6°C. The arenas (Fig. 7) with cucumber leaf discs were used in the experiment. The predator was tested on the life stages: egg, N_3 nymph, 4-5-day-old adult males and females. At least 280 eggs or individuals from each desired life stage were preconditioned for 5 h at temperature 20°C, where every 30 eggs were kept in an arena, and the predatory individuals of the other life stages were singly reared in the arenas with *T. tabaci* (nymphs + adults) as prey. After preconditioning, they were transferred to new arenas with fresh leaf discs, 30 eggs per arena, or 5 predatory individuals from the same life stage in an arena with prey offered. These arenas were distributed to temperatures of 3 and 6°C. Afterward, every 3 days, the eggs and predatory individuals were transferred to new arenas with fresh leaf discs, in order to keep good moisture. After being kept for 3, 15, 30, 45, 60, 75 and 90 days under the low temperatures, 30 eggs and 20 individuals of each predatory stage were sampled from each temperature. The sampled eggs and predatory individuals were transferred to 28°C temperature for death identification. Mixed population of *T. tabaci* was offered as prey. The eggs were kept

for development, and daily checked under binocular microscopes until they had been observed for 20 days after sampling. The eggs which fail to hatch in 20 days and get rotten were identified as died, and noted. In the samplings of other tested life stages, the predatory individuals which could not recover to move in 3 days were identified dead and noted.

2.1.8 Prey preference by *Geocoris ochropterus*

Experiments were conducted to investigate the prey preference by N_2, N_4 instars and female adult of *G. ochropterus* for different prey ages of *F. occidentalis*, *T. tabaci* and *G. ficorum* in laboratory at temperature 25±1^{o}C, relative humidity of 60±10% and a photoperiod of 16:8 h (L:D). The preference by the predators for different prey species was also experimented here.

2.1.8.1 Prey-age preference

Cucumber leaf discs were used in the experiment with *F. occidentalis* and *T. tabaci* as prey, while leaf discs of *F. microcarpa* were used in the experiment with *G. ficorum* as prey. Individuals of N_2, N_4 instars and 10-day-old female adults of *G. ochropterus* were placed singly on leaf discs in arena (Fig. 7). From the same thrips species, 30 individuals of L_1, L_2 larvae and adult females were simultaneously offered as prey in each arena. After 24 h, the predatory individuals were transferred to new arenas with fresh prey offer. The number of consumed prey individuals was checked daily. To avoid the possibility that the predator bug might get adapted to a certain prey age, they had been reared with different prey ages simultaneously offered as prey before the experiments began. The experiments were conducted during the entire developmental period of N_2, N_4 instars as well as for 3 days with 10-day-old female adults of *G. ochropterus*. Ten replicates were set for each tested age of *G. ochropterus* with each thrips species as prey.

2.1.8.2 Prey-species preference

To test the prey preference of *G. ochropterus* for different prey species, the individuals of desired age from 5 prey species, which could present together in vegetable plantation in the agricultural ecosystem, were prepared in laboratory. They were 1-2-days-old nymphs of *A. gossypii*, pupae of *B. tabaci*, adult females of *T. urticae*, *F. occidentalis* and *T. tabaci*. The preference was

determined in the arenas (Fig. 7). Cucumber leaf discs, each contained 20 pupae of *B. tabaci*, were placed singly onto the agar gel layer in each arena. Twenty individuals of desired age from the other 4 prey species were added to *B. tabaci* pupae on the cucumber leaf disc in each arena. Afterwards, ten predatory individuals of each N_2, N_4 instars and 10-day-old female adult of *G. ochropterus* were singly introduced into the arenas. After 24 h, the predatory individuals were transferred to new cages with fresh prey offer. The number of consumed prey individuals, which were empty of body fluid, as well as the prey species were recorded under binocular microscope.

2.1.9 Effect of the different nutritions on *Geocoris ochropterus*

Information about the survival of *G. ochropterus* at different nutritions is valuable for the practice not only to estimate what will happen to the predator in fields at stress condition, but also to rear the predator in mass. Experiments were conducted in laboratory to investigate how long N_4 instar and adult of *G. ochropterus* would survive at the different nutrition conditions:

(A) no leaf + no prey,

(B) leaf + no prey,

(C) no leaf + *T. tabaci*,

(D) leaf + *B. tabaci*,

(E) leaf + *T. tabaci*,

(F) 10% honey.

The freshly molted N_4 nymphs, and 2-day-old adult females as well as males of *G. ochropterus* were tested with each nutrition condition in the arenas (Fig. 7) at temperature 25±1^{o}C, relative humidity of 60±10% and a photoperiod of 16:8 h (L:D).

Effect on N_4 instar

According to each kind of the nutrition conditions, cucumber leaf disc without insects infested, mixed population of *T. tabaci*, cucumber leaf discs infested with mixed population of *B. tabaci* and 10% honey emulsion were offered in the arenas. The predatory nymphs were divided into 6 groups of 12 individuals, in order to prepare a group of predatory nymphs for a kind of nutrition condition. The predatory individuals within each group were placed singly in each arena with

desired nutrition condition. After that, the treated predators were daily transferred into new arenas with the appropriate nutrition condition until the predators died or grew into next instars. The old arenas were checked for the mortality and molting of N_4 nymphs of *G. ochropterus*.

Effect on the adults

Two-day-old female and male adults of *G. ochropterus* were separately divided into 6 groups of 12 individuals, a group from each sex for a kind of nutrition. The predatory individuals from a group were singly introduced into arenas with a given nutrition. After that, the treated predators were daily transferred into new arenas with the appropriate nutrition condition until the predators died. The old arenas were checked for the mortality of adult females and males of *G. ochropterus*.

2.1.10 Cannibalism of *Geocoris ochropterus*

Predatory individuals of *G. ochropterus* were found to attack each other. This sparked interest to research the cannibalism (CANN) of *G. ochropterus* with prey absent or present. The method was similar to that described by LUCAS et al. (1998) with some modification.

In the experiment on CANN of *G. ochropterus*, seven combinations of predatory individuals would be used:

(A) one N_3 nymph,
(B) one adult male,
(C) one female adult,
(D) one female adult vs. five eggs,
(E) one female adult vs. one N_3 nymph,
(F) one female adult vs. one male adult,
(G) one female adult vs. one female adult.

The combinations A, B and C were used as control treatments.

In the absence of prey

According to each of the seven combinations (A-G), 2-day-old eggs, freshly molted N_3 nymphs,

3-day-old adult females and males of *G. ochropterus* were used. Predators were starved for 24 h before testing in order to increase their motivation for predation. This is similar to the methods described by other researchers mentioned above.

The experiments were carried out in the arenas (Fig. 7) at 25±1^{o}C temperature, 60-70% RH and under a photoperiod of 16:8 h (L:D). Insects involved in each combination were introduced on the cucumber leaf discs in the arenas. After 24 h, the number of living and dead insects was counted. Consumed eggs were empty and easy to check under binocular microscope. Fifteen replicates per combination were carried out.

A level of CANN (CL; proportion of replicates with CANN over the total number of replicates) as well as an index of symmetry (SI; proportion of replicates in which one given life stage was eaten over the total number of replicates in which either of the pair of individuals was eaten) were calculated for each combination and adjusted by the mortality in control treatments. The indices of symmetry for each tested pair were compared to a theoretical index of 50% corresponding to a symmetric interaction using a chi-square test (LI et al. 2005). The mean number of eggs consumed in each treatment was analyzed using a one-way ANOVA.

In the presence of prey

In this section, the seven combinations (A-G) of predatory individuals were used here with 90 L_2 larvae of *T. tabaci* offered as prey. The experiment was carried out in the similar procedure in the experiment on the cannibalism with absence of prey. Besides the level of CANN (CL) and index of symmetry (SI), the number of *T. tabaci* consumed in each combinations were also recorded and compared using a one-way ANOVA. Each combination was replicated 15 times.

2.1.11 Intraguild predation between *Geocoris ochropterus* and *Orius similis*

To enhance the chance for using *G. ochropterus* in a biological control program, the knowledge about how it reacts to another predator is valuable. The predator bug *O. similis* is an important biological control agent against the pest insects on vegetable. Therefore, intraguild predation (IGP) between *G. ochropterus* and *O. similis* was investigated here. The method was similar to that described by LUCAS et al. (1998) with some modification. Two sets of experiments were conducted to examine the IGP: in the absence and presence of prey.

In the absence of prey

To carry out experiment on IGP between *G. ochropterus* and *O. similis* in the case with prey absent, eight combinations of the two predatory species were used:

(A) one N_3 nymph of *O. similis*,

(B) one female adult *O. similis*,

(C) one N_3 nymph of *G. ochropterus*,

(D) one female adult *G. ochropterus*,

(E) five eggs of *G. ochropterus* vs. one female adult of *O. similis*, based on different mobility,

(F) one N_3 nymph of *G. ochropterus* vs. one female adult *O. similis*, based on different life stage,

(G) one female adult *G. ochropterus* vs. one N_3 nymph of *O. similis*, based on approximately similar size,

(H) one female adult of *G. ochropterus* vs. one female adult *O. similis*, based on same life stage.

According to each combination, eggs of *G. ochropterus*, freshly molted N_3 nymphs, 3-day-old adult females of the two predatory bug species were used. Predators were starved for 24 h prior to testing in order to increase their motivation for predation, which was similar to the methods described by other researchers mentioned above.

The experiments were carried out in arenas (Fig. 7) at 25±1^{o}C temperature, 60-70% RH and under a photoperiod of 16:8 h (L:D). Insects involved in each combination were introduced on the cucumber leaf discs in the arenas. After 24 h, the number of living and dead insects was counted. Consumed eggs were empty and easy to check under binocular microscope. Experiments were replicated 15 times for each combination.

A level of IGP (IL; proportion of replicates with IGP over the total number of replicates) as well as an index of symmetry (SI; proportion of replicates in which one given predator was eaten over

the total number of replicates in which one or the other predator was eaten) for each combination were calculated and adjusted by the mortality in control treatments. The indices of symmetry for each tested pair were compared to a theoretical index of 50% corresponding to a symmetric interaction using a chi-square test (LI et al. 2005). The mean number of eggs consumed in each treatment was analyzed using a one-way ANOVA.

In the presence of prey

To investigate the IGP between *G. ochropterus* and *O. similis* with presence of *T. tabaci* as prey, the experiment procedure in the absence of prey was modified and employed here. Each of the eight combinations (A-H) was here offered 70 L_2 larvae of *T. tabaci* as prey. Besides the level of IGP (IL) and index of symmetry (SI), the number of *T. tabaci* consumed in each of the eight combinations were also recorded and compared using a one-way ANOVA. Fifteen replicates were carried out for each combination.

2.2 Greenhouse experiments

2.2.1 Efficiency of *Geocoris ochropterus* against *Frankliniella occidentalis*

From April to May of the year 2007, a greenhouse experiment was conducted to evaluate the efficiency of *G. ochropterus* in controlling *F. occidentalis* on sweet pepper plants, *Capsicum frutescens* L.(syn.C.annuum L.) var. grossum Bailey. The experiment were conducted in 3 separated glass cabins (cabin I, II and III), each with an area about 3 m×3 m in Fuzhou City. The cabins were totally sealed to prevent immigration and emigration of insects.

To establish *F. occidentalis* populations for the experiment, twenty-one potted sweet pepper plants, each with 12-15 cm in high and 6-7 fully developed true leaves, were placed in rows of 7 in each cabin. The pepper plants were arranged to be 30 cm distant from each other and 40 cm from the walls of the cabin. Four upper leaves of each plant in the three cabins were infested with a total number of 20 individuals of 5-day-old female adults of *F. occidentalis*, which were kept with male adult for 5 days after emergence. Onto each of the 4 upper leaves, 5 female adults of the thrips were transferred.

Mated ten-day-old *G. ochropterus* were previously reared for the release in the glass cabins. In cabin I, a total of 21 females and 21 males, with one female and one male per plant, were released one week after the plant had been infested with *F. occidentalis*. Two weeks after infesting with *F. occidentalis*, the same number of *G. ochropterus* females and males was released in cabin II. No predators were released in cabin III, which served as a control treatment.

Three pepper plants were randomly sampled from each cabin starting from the first week after infestation of *F. occidentalis* and then once weekly. The number of *G. ochropterus* (eggs + nymphs + adults) and *F. occidentalis* (adults + larvae) existing on the selected plants was recorded directly on the plants with magnifying lens. The experiment continued 7 weeks till all plants were tested.

2.2.2 Efficiency of *Geocoris ochropterus* against *Thrips tabaci*

From October to December of the year 2007 in Fuzhou City, the efficiency of *G. ochropterus* in controlling *T. tabaci* was evaluated on sweet pepper plants under greenhouse condition. The experiment was conducted with same pepper variety and procedure as used in capital 2.2.1, except that the thrips species *F. occidentalis* was replaced with *T. tabaci*.

2.2.3 Efficiency of *Geocoris ochropterus* against *Gynaikothrips ficorum*

From June to July of the year 2007, a releasing experiment was also taken to estimate the efficiency of *G. ochropterus* against *G. ficorum* under greenhouse condition in Fuzhou City. To prepare the host trees in pot for the experiment, the stems in similar size (0.3-0.5 cm in diameter and 20 cm in length) were detached from *F. microcarpa*, and cultured by the method of cuttage with 1 stem in one pot (12 cm in diameter and 12 cm in high) under same greenhouse climatic condition. After the trees in pot grew for a period of time (about 8 months), 63 pots of the young banyan were selected to be used (Fig. 8).

The procedure employed in the experiment was similar to that used in capital 2.2.1, except that the host plants were replaced with young banyan trees in pots, and the thrips species was replaced with *G. ficorum*.

Fig. 8: Young banyan trees (*Ficus microcarpa*) in pots for greenhouse experiment

2.3 Statistical analysis

In all the experiments except those on cannibalism and intraguid predation by predators, analysis of variance (ANOVA) was used for statistic evaluation. The general linear models of analysis of variance were used to analyze the experiments in one-way comparison of mean. To perform multiple comparison, ANOVA appropriate for factorial in completely randomize design were used. One-or two-factor-ANOVA was conducted to detect differences among means. In the case of differences among means were detected, the second step was then to determine the significant differences among the means usually at a probability level of $p \leq 5\%$. Among several means, the Duncan's multiple rang test was used (GOMEZ and GOMEZ 1984). In the case of comparing between two means only, T-test was conducted (ANONYMOUS 2002). Small and capital letters represent significant difference parameters in the figures and tables.

In experiment on cannibalism and intraguid predation by predators, the indices of symmetry for each tested pair were compared to a theoretical index of 50% corresponding to a symmetric interaction using a test of conformity (LI et al. 2005).

The statistical analysis was done using the China-DPS program (TANG 2001).

3 RESULTS

3.1 Laboratory experiments

3.1.1 Biology and prey consumption of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* at temperature 25°C

3.1.1.1 With *Frankliniella occidentalis* as prey

This part deals with the results of the experiments on the biology and prey consumption of the four predatory bug species *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* with *F. occidentalis* as prey.

3.1.1.1.1 Biology

The experiments were carried out to determine the embryonic and nymphal development, mortality, longevity and fecundity of the four predatory bug species with *F. occidentalis* as prey.

Embryonic development

Table 1 lists the embryonic developments of the four predatory bug species at temperature 25±1°C. The results show significant differences in embryonic developmental period among the four predatory bug species. The embryonic developmental period of *G. ochropterus* was the longest with a mean of 17.2 days, that of *S. subula* was the second with a mean of 12.6 days, the third was *M. moraguesi* with a mean of 5.8 days, *O. similis* was shortest with a mean of 3.6 days.

Tab. 1: Mean embryonic developmental period of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* on bean or cucumber leaves at temperature 25±1°C

Predatory species	Host plant	n	Embryonic developmental period (days)	
			Mean ± SE	Min. - Max.
G. ochropterus	Bean	21	17.2 ± 0.2 d	16 - 18
M. moraguesi	Cucumber	23	5.8 ± 0.2 b	5 - 7
O. similis	Bean	25	3.6 ± 0.1 a	3 - 4
S. subula	Bean	21	12.6 ± 0.2 c	11 - 14

Means in columns followed by different letters are significantly different at p≤1% (one-factor ANOVA)

Nymphal development

With L_2 *F. occidentalis* as prey, all tested predatory bug species but *S. subula* were able to complete nymphal development. *G. ochropterus*, *M. moraguesi* and *O. similis* went through 5 instars with different developmental periods during the nymphal stage (Tab. 2). Without regarding *S. subula*, the longest instar was N_5 in *G. ochropterus* with a mean developmental period of 11.8 days, while the shortest instar was N_1 in *O. similis* with a mean period of 1.6 days. The total developmental period from N_1 to adult was longest in *G. occidentalis* with a mean of 37.3 days, and second longest in *M. moraguesi* with 19.9 days. It was shortest in *O. similis* with 13.7 days. *S. subula* could complete development in the first 4 instars, but failed in N_5 instar where it showed high mortality and died all before adult emergence.

Tab. 2: Mean nymphal developmental period of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with L_2 *Frankliniella occidentalis* as prey on bean or cucumber leaves at temperature 25±1°C

Predatory species	Host plant	n	Developmental period (days)					Total (N_1 to adult) (days) Mean±SE
			N_1 Mean±SE	N_2 Mean±SE	N_3 Mean±SE	N_4 Mean±SE	N_5 Mean±SE	
G. ochropterus	Bean	20	7.6±0.1 bA	5.8±0.3 cdB	5.5±0.1 d B	6.5±0.2 cB	11.8±0.5 aA	37.3±0.6 A
M. moraguesi	Cucumber	20	3.7±0.2 bB	3.0±0.1 bcC	2.8±0.2 c C	3.8±0.1 bC	6.6±0.2 aB	19.9±0.3 B
O. similis	Bean	20	1.6±0.1 dC	2.3±0.1 cdD	2.5±0.1 bcC	3.1±0.2 bD	4.2±0.1 aC	13.7±0.2 C
S. subula	Bean	20	8.5±0.3 bA	8.4±0.3 b A	8.1±0.3 b A	13.5±0.8 aA	†	

Means in columns with different small letters indicate significant differences among different instars within the same predatory species, while the means with different capital letters indicate significant differences among different predatory species within the same instars at $p \leq 5\%$ (two-factor ANOVA)

Mortality

The mortalities of eggs and nymphs of the four predatory species during development are shown in Fig. 9. At temperature 25±1°C, mortality during egg stage was very low for each species. All of the eggs from each predatory bug species successfully finished the embryonic development, except that eggs of *O. similis* were recorded a mortality of 8%. During the nymphal development, *S. subula* showed high mortality in N_4 and N_5 instars, and its total mortality from N_1 instar to adult emergence was 100%. This indicated that *S. subula* was not able to complete nymphal

development by feeding on *F. occidentalis* as prey. Total mortality from N_1 instar to adult emergence was 35% for *G. ochropterus*, 25% for *M. moraguesi* and 15% for *O.similis*.

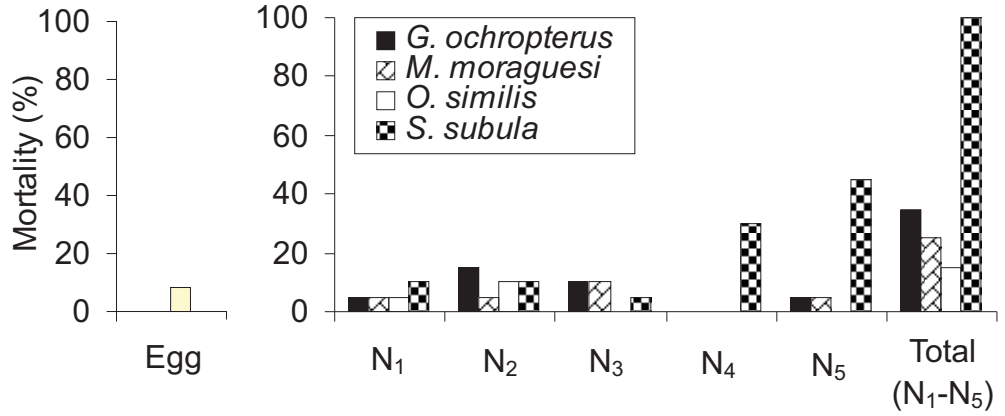

Fig. 9: Percentage mortality of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* during embryonic and nymphal development with L_2 *Frankliniella occidentalis* as prey on cucumber leaves for *Montandoniola moraguesi* and on bean leaves for the other predatory species at temperature 25±1°C

Sex ratio

With mixed population of *F. occidentalis* as prey on cucumber leaves at temperature 25±1°C, the percentage of adult females and males was 58.7% (♀♀) and 41.3% (♂♂) for *G. ochropterus*, 48.6% (♀♀) and 51.4% (♂♂) for *M. moraguesi*, as well as 55.4% (♀♀) and 44.6% (♂♂) for *O. similis* (Fig. 10).

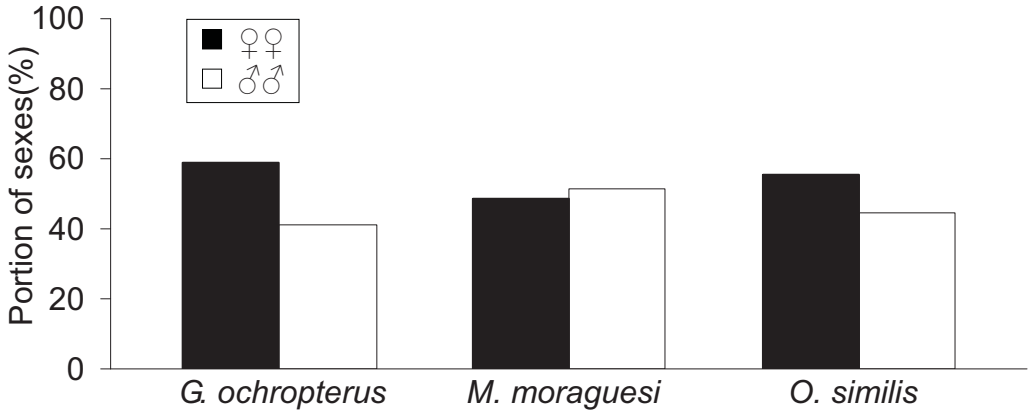

Fig. 10: Percentage portion of sexes of *Geocoris ochropterus*, *Montandoniola moraguesi* and *Orius similis* with mixed population of *Frankliniella occidentalis* as prey on cucumber leaves at temperature 25±1°C

Longevity

As shown in Fig. 11, the mean longevity of *G. ochropterus* was 63.3 (♀♀) and 57.1 (♂♂) days with mixed population of *F. occidentalis* as prey at 25±1°C temperature. It was significantly longer than those of the other 3 predatory species. Longevities of *M. moraguesi* (♀♀: 32.6 days, ♂♂: 31.7 days) and *O. similis* (♀♀: 31.7 days, ♂♂: 37.8 days) were similar. *S. subula* lived for a mean longevity of 12.7 days (♀♀) and 13.1 days (♂♂), the shortest among the tested species.

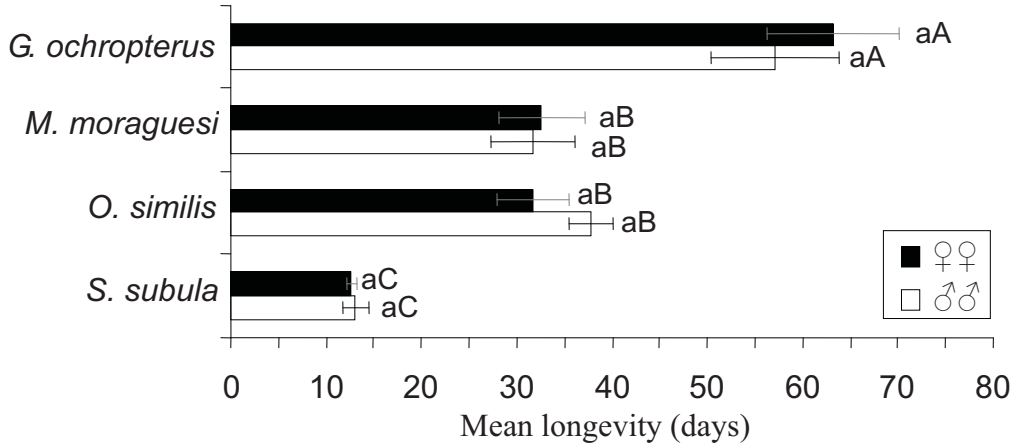

Fig. 11: Mean longevity of adult females and males of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with mixed population of *Frankliniella occidentalis* as prey on cucumber leaves at temperature 25±1°C. [Bars with different small letters indicate significant differences between the female and male within the same predatory species, while bars with different capital letters indicate significant differences among different predatory species within the same sex at p≤5% (two-factor ANOVA)]

Fecundity

As parameters of fecundity, the periods of pre-oviposition, oviposition and post-oviposition, as well as the daily and total number of eggs were observed with mixed population of *F. occidentalis* as prey at temperature 25±1°C.

Oviposition period

The periods of pre-oviposition, oviposition and post-oviposition of the four predatory bug species are illustrated in Tab. 3. With a mean of 8.6 days, the pre-oviposition period of *S. subula* was significantly longer than those of the other predatory species. The period of *G. ochropterus* was a mean of 7.5 days, also significantly longer than that of *M. moraguesi* and *O. similis* (5.5

and 3.4 days, respectively). The mean oviposition period of *G. ochropterus* was a mean of 51.2 days, significantly longer than the other tested predatory bug species. *M. moraguesi* and *O. similis* showed similar oviposition periods (23.4 and 23.8 days, respectively). *S. subula* was recorded the shortest mean oviposition period (3.5 days) among the tested predatory bug species. There were no significant differences in the mean period of post-oviposition between the four predatory species.

Tab. 3: Mean periods of pre-oviposition, oviposition and post-oviposition of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with mixed population of *Frankliniella occidentalis* as prey on cucumber leaves at temperature 25±1°C.

Predator species	n	Period of (days)					
		Pre-oviposition		Oviposition		Post-oviposition	
		Mean±SE	Min.-Max.	Mean±SE	Min.-Max.	Mean±SE	Min.-Max.
G. ochropterus	10	7.5±0.2 b	7 -8	51.2±6.6 a	5 - 67	3.6±4.6 a	0 - 15
M. moraguesi	10	5.5±0.2 c	5 - 6	23.4±3.8 b	1 - 34	3.0±1.2 a	0 - 12
O. similis	10	3.4±0.2 d	3 - 5	23.8±3.6 b	2 - 39	3.5±1.7 a	0 - 18
S. subula	10	8.6±0.2 a	8 -9	3.5±0.4 c	1 - 5	1.2±0.5 a	0 - 4

Means in columns with different letters indicate significant differences between the predator species at p≤5% (one-factor ANOVA).

Daily and total fecundity

At temperature 25±1°C, *G. ochropterus* females started oviposition on 8th day after adult emergence with a mean of 0.5 eggs/♀(Fig. 12). Hereafter, the mean daily fecundity on different days fluctuated between 0.1 and 7.2 eggs/♀ until the oviposition stopped on the 74th day after adult emergence. *M. moraguesi* females daily laid 0.3-3.8 eggs/♀ during the oviposition period. Oviposition of *O. similis* females started with a mean of 6.3 eggs/♀ on 4th day, and reached a maximum of 9.0 eggs/♀ on 9th day. Its daily fecundity then decreased in fluctuation until it stopped on 43rd day. The mean number of eggs laid by *S. subula* on each day fluctuated between 2.0 and 6.0 eggs/♀/day during the ovipostion period. Total number of eggs laid by *G. ochropterus* was mean 112.1 eggs/♀, similar to that of *O. similis* (104.6 eggs/♀), while significantly higher than those of *M. moraguesi* (34.6 eggs/♀) and *S. subula* (15.7 eggs/♀).

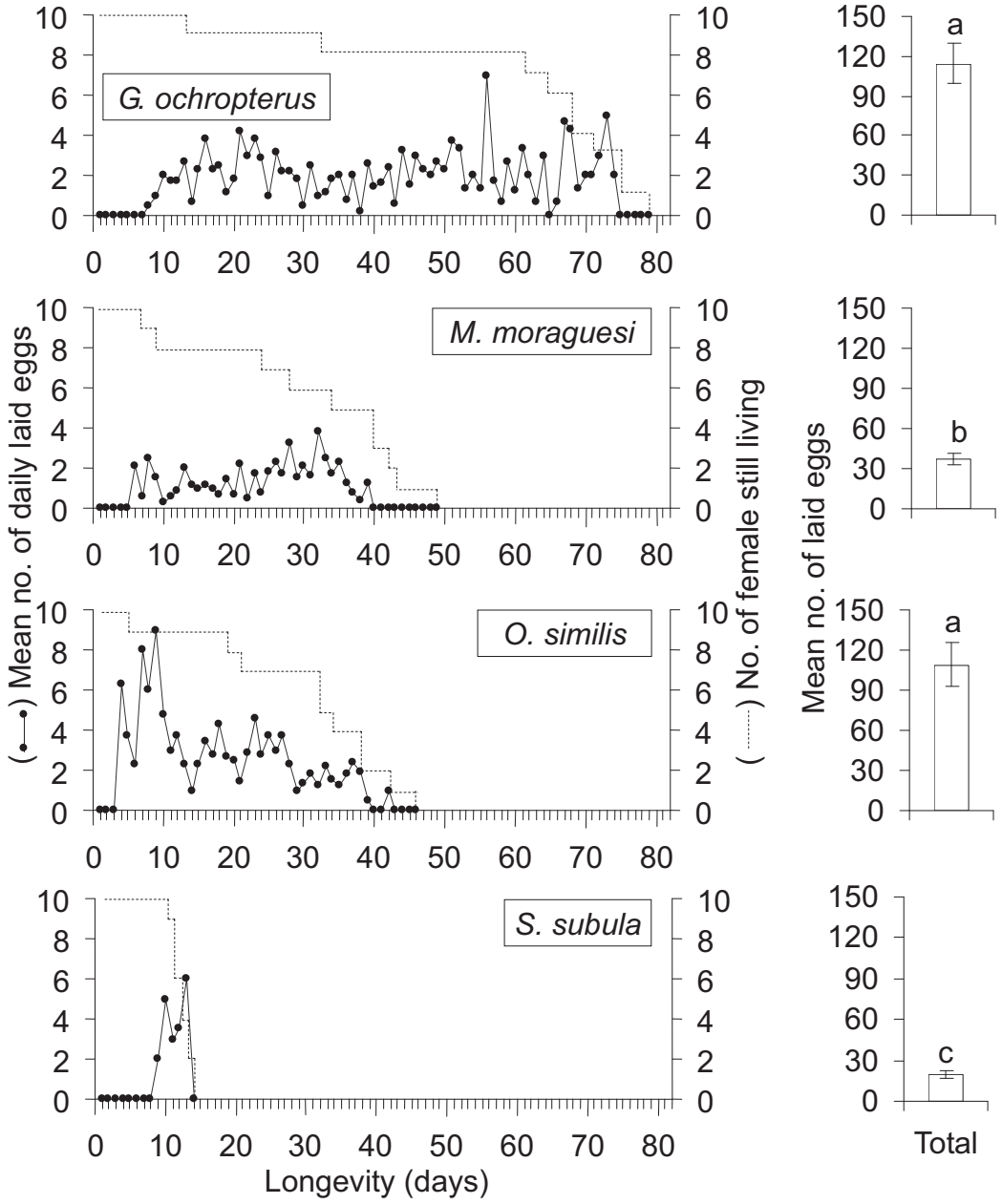

Fig. 12: Mean number of daily laid eggs by *Geocoris ochropterus*, *Montandoniola moraguesi*, *Scipinia subula* and *Orius similis* by feeding on mixed population of *Frankliniella occidentalis* as prey on cucumber leaves at temperature 25±1°C. [Bars with small letters indicate significant differences among different predatory species at p≤5% (one-factor ANOVA)]

3.1.1.1.2 Prey consumption

The daily prey consumption by the four tested predatory bug species were investigated throughout their entire nymphal development as well as the first 15 days after the emergence of their adult females and males. The experiments were carried out with L_2 *F. occidentalis* as prey at temperature 25±1°C, relative humidity of 60±10% as well as a photoperiod of 16:8 h (L:D) under laboratory condition.

Prey consumption by nymphal predators

Figure 13 shows the prey consumption by the predatory nymphs during the entire development with L_2 *F. occidentalis* as prey at temperature 25±1°C.

The nymphs of *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* started feeding in a few hours after hatching from the eggs. The mean daily prey consumption by *G. ochropterus* nymphs was 1.7 thrips on 1st day after hatching and increased gradually to reach a peak of 15.8 thrips by the N_5 instar on 41st day. While *M. moraguesi* nymphs consumed a mean of 0.9 thrips on 1st day, and its mean daily prey consumption reached a peak of 7.4 thrips on 15th day. When *O. similis* nymphs were tested as predator, the mean daily prey consumption was 1.0 thrips on 1st day after hatching and increased thereafter to a maximum of 5.7 thrips by the N_5 instar on 14th day. *S. subula* nymphs consumed a minimum of 2.2 thrips on 1st day and a maximum of 17.5 thrips on 39th day. Afterward, all nymphs of *S. subula* died before adult emergence.

The mean daily prey consumption of *G. ochropterus* through out the nymphal development was averaged 6.8 thrips, significantly higher than that of *M. moraguesi* (3.9 thrips) and *O. similis* (2.8 thrips).

During the entire nymphal development, mean total prey consumption by *G. ochropterus* was 270.2 thrips. It was significantly higher than that of *M. moraguesi* (84.4 thrips) and *O. similis* (40.4 thrips).

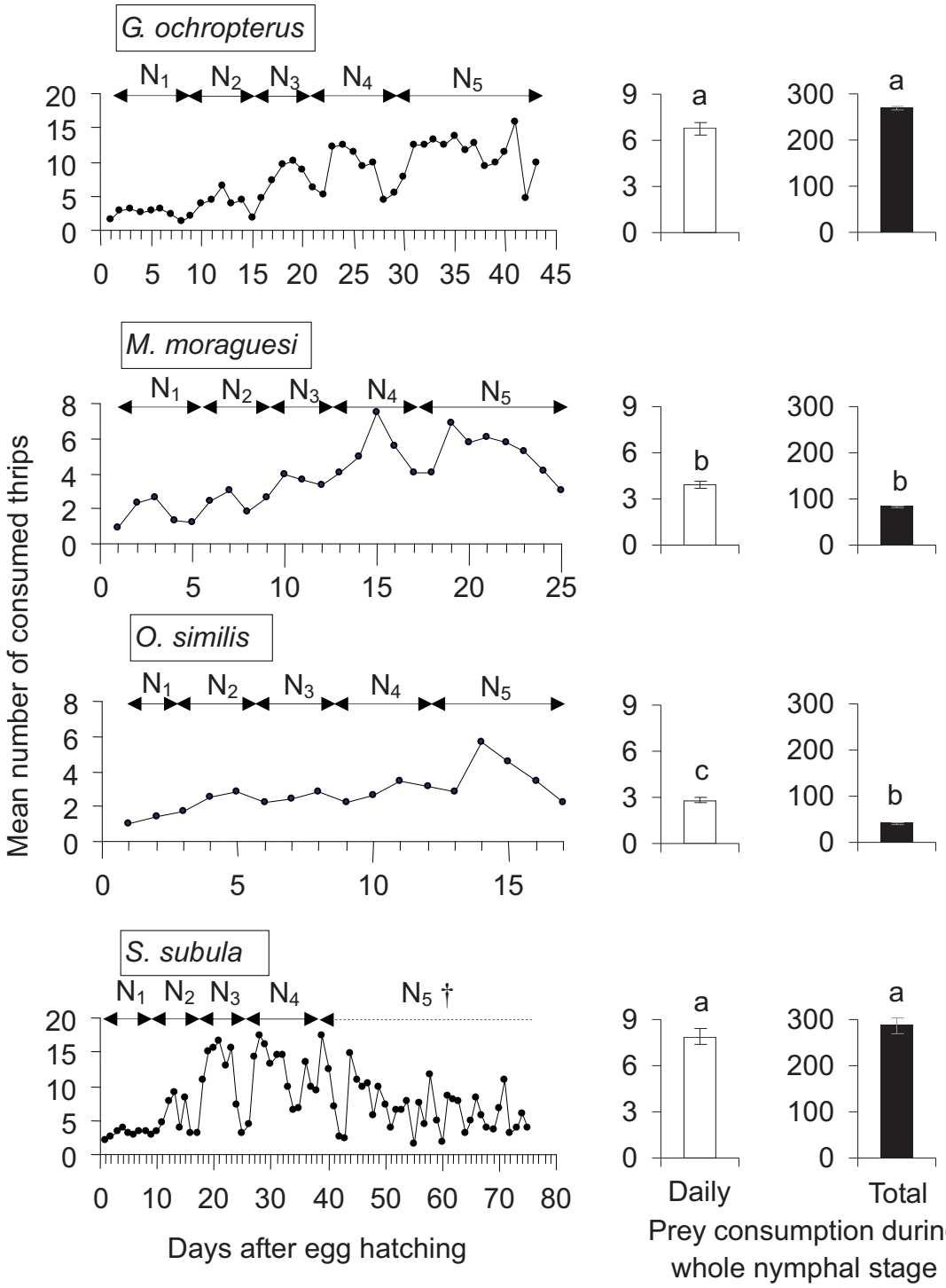

Fig. 13: Mean daily and total prey consumption by nymphs of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* during development on L_2 *Frankliniella occidentalis* at 25±1°C. [Bars with different letters indicate significant differences among different predatory species at p≤5%(one-factor ANOVA)]

Prey consumption by adult predators

The mean daily and total prey consumption by adult females and males of the four tested predatory species is demonstrated in Fig. 14.

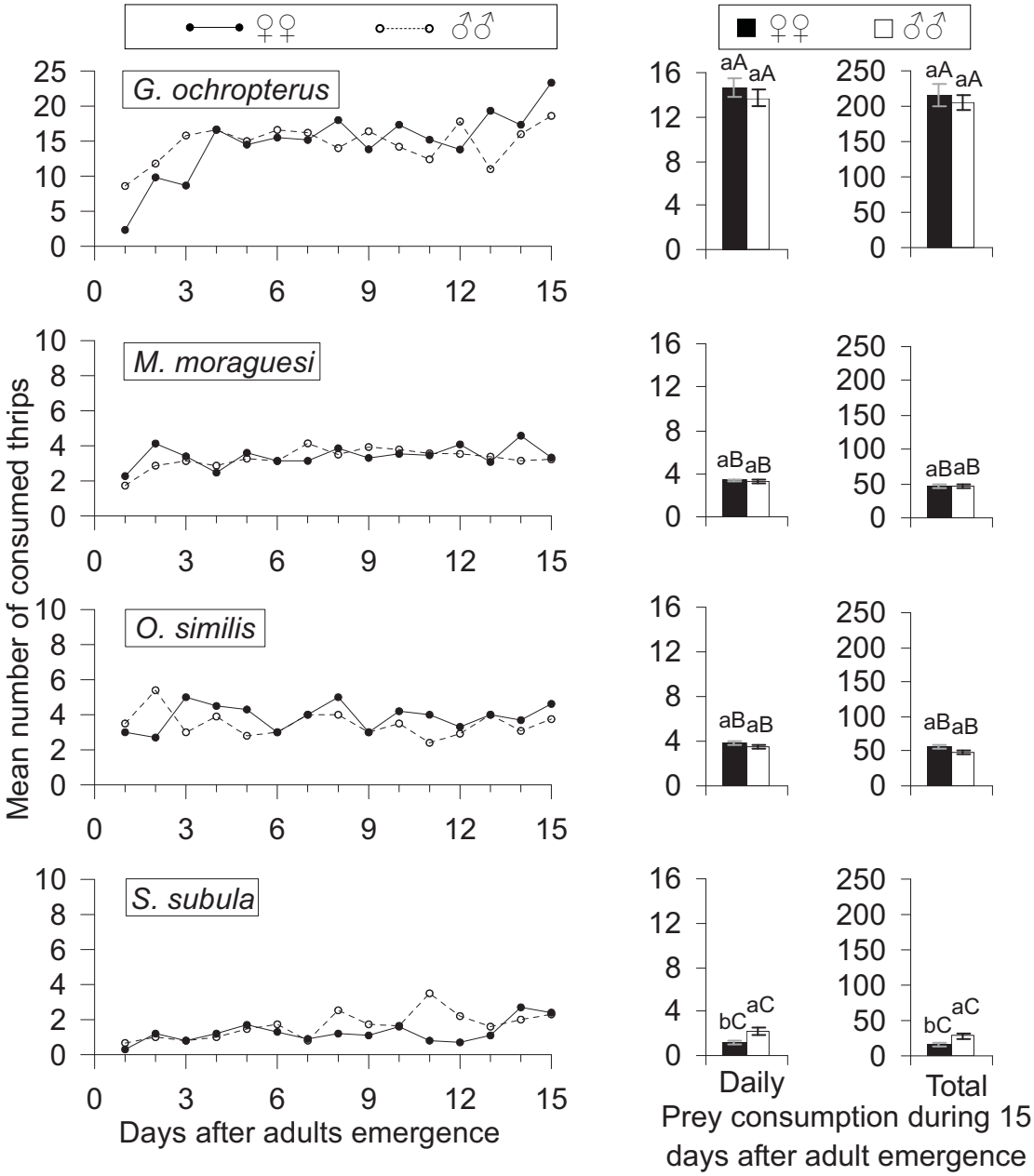

Fig. 14: Mean daily and total prey consumption by adults of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* by feeding on L_2 *Frankliniella occidentalis* as prey on cucumber leaves at temperature 25±1°C. [Bars with different small letters indicate significant differences between the female and male within the same predatory species. Bars with different capital letters indicate significant differences among different predatory species within the same sex at p≤5% (two-factor ANOVA)]

During the first 15 days after adult emergence, the mean daily prey consumption by adult *G. ochropterus* on each day fluctuated between from 2.7-23.1 thrips/♀, or 8.6-18.6 thrips/♂. Adult *M. moraguesi* daily consumed 2.3-4.9 thrips/♀, or 1.8-4.1 thrips/♂. With adult *O. similis* as predator, the mean daily prey consumption on each day varied from 2.7-5.0/♀, or 2.4-5.4 thrips/♂. In the first 15 days after adult emergence, *S. subula* daily consumed 0.2-2.7 thrips/♀, or 0.6-3.7 thrips/♂.

The daily prey consumption by adult of *G. ochropterus* was significantly higher than the prey consumption by the other 3 predatory species. During the first 15 days after adult emergence, the number of thrips daily consumed by *G. ochropterus* was averaged 14.7 thrips/♀ and 13.7 thrips/♂. Daily prey consumption by *M. moraguesi* was 3.4 thrips/♀ and 3.2 thrips/♂, similar to the mean daily consumption by *O. similis* (3.9 thrips/♀ and 3.5 thrips/♂). *S. subula* daily consumed the significantly lowest number of thrips.

G. ochropterus consumed a mean total of 216.0 thrips/♀ and 205.2 thrips/♂ over 15-day-period after the predatory adult emergence, significantly higher than *M. moraguesi* with the total mean of 46.6 thrips/♀ and 46.2 thrips/♂. The mean total prey consumption of *G. ochropterus* was also significantly higher than that of *O. similis* (57.1 thrips/♀ and 48.1 thrips/♂). There was no significant difference between *M. moraguesi* and *O. similis* in terms of the mean total consumption. The total prey consumption of *S. subula* was the significantly lowest among the four predatory species with a mean of 15.1 thrips/♀ and 27.9 thrips/♂.

3.1.1.2 With *Thrips tabaci* as prey

In this section, the biology and prey consumption of the four predatory bug species *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* were investigated with *T. tabaci* as prey.

3.1.1.2.1 Biology

The results of the experiments revealed the immature developmental period, mortality, sex ratio, longevity and fecundity of the four predatory species.

Embryonic development

The embryonic developmental period among the four tested predatory species was significantly different (Tab. 4). *G. ochropterus* eggs hatched in a mean of 16.8 days, slowest among the tested predatory species. *S. subula* completed embryonic development in a mean of 13.0 days, slower than *M. moraguesi* (5.2 days) and *O. similis* (3.1 days).

Tab. 4: Mean embryonic developmental period of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* on cucumber leaves at temperature 25±1°C

Predatory species	n	Embryonic developmental period (days)	
		Mean±SE	Min. - Max.
G. ochropterus	21	16.8±0.2 d	15 - 18
M. moraguesi	23	5.2±0.2 b	5 -7
O. similis	23	3.1±0.3 a	3 - 5
S. subula	21	13.0±0.2 c	10 - 14

Means in columns followed by different letters are significantly different at p≤1% (one-factor ANOVA)

Nymphal development

By feeding on L_2 *T. tabaci* as prey, all the tested predatory bug species were able to grow from freshly hatched nymphs to adults with 5 instars, except that *S. subula* displayed high mortality in N_5 instar and its nymphs all died before adult emergence (Tab. 5). Without regarding *S. subula*, N_5 instar was significantly longer than the other instars within same predatory species. Its developmental period was from 3.4 days in *O. similis* to 10.3 days in *G. ochropterus*. N_1 instar was the shortest among the instars of *O. similis*, but second longest among the instars of *G. ochropterus* or *M. moraguesi*. The mean total developmental period from N_1 to adult emergence was significantly longer in *G. ochropterus* (35.5 days) than in *M. moraguesi* (18.6 days) and *O. similis* (12.8 days). The total period of *M. moraguesi* was also significantly longer than *O. similis*.

Tab. 5: Mean nymphal developmental period of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis*, and *Scipinia subula* with L_2 *Thrips tabaci* as prey on cucumber leaves at temperature 25±1°C

Predatory species	n	Developmental period (days)					Total (N_1 to adult) (days) Mean±SE
		N_1 Mean±SE	N_2 Mean±SE	N_3 Mean±SE	N_4 Mean±SE	N_5 Mean±SE	
G. ochropterus	20	7.4±0.1 b B	5.9±0.1 cdB	5.6±0.1 d B	6.3±0.2 c B	10.3±0.2 aA	35.5±0.3 A
M. moraguesi	20	3.3±0.1 bcC	2.5±0.1 d C	2.7±0.1 cdC	3.8±0.2 b C	6.4±0.1 aB	18.6±0.3 B
O. similis	20	1.5±0.1 d D	2.3±0.1 c C	2.5±0.1 bcC	3.0±0.2 abD	3.4±0.3 aC	12.8±0.6 C
S. subula	20	8.1±0.2 c A	8.2±0.2 bcA	8.8±0.2 b A	12.7±0.3 a A	†	

Means in columns with different small letters indicate significant differences among different instars within the same predatory species, while the means with different capital letters indicate significant differences among different predatory species within the same instars at p≤5% (two-factor ANOVA)

Mortality

As shown in Fig. 15, all eggs of the tested predatory bug species could grew into nymphs with a mortality of 4.3% in *O. similis*. The freshly Nymphs of *G. ochropterus*, *M. moraguesi* and *O. similis* could successfully develop into adults, with a total mortality of 20.0, 30.0 and 20.0% from N_1 to adult emergence, respectively. While *S. subula* nymphs failed to complete the entire nymphal development. Mortality of *S. subula* occurred mostly in N_4 and N_5 instars. In the rested predatory species, N_1 nymphs died easier than the other instars.

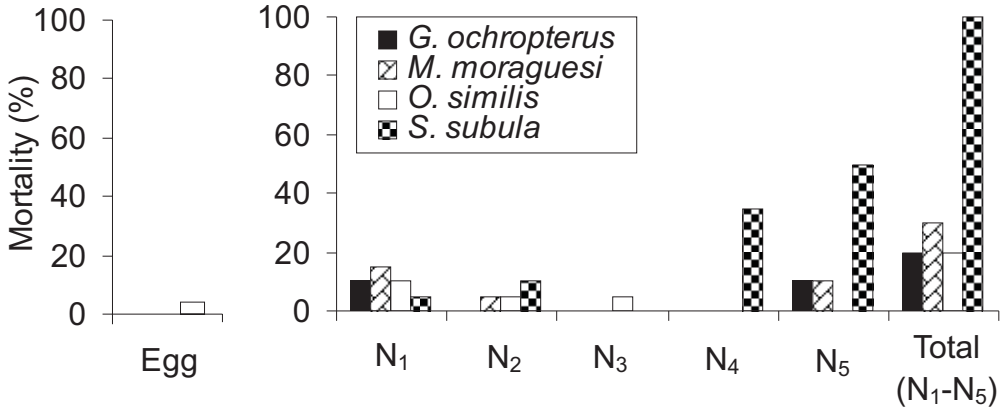

Fig. 15: Percentage mortality of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* during embryonic and nymphal development with L_2 *Thrips tabaci* as prey on cucumber leaves at temperature 25±1°C

Sex ratio

With *T. tabaci* as prey at temperature 25±1°C, the percentage portion of females was 51.5% (♀♀) for *G. ochropterus*, 53.9% (♀♀) for *M. moraguesi* and 47.9% (♀♀) for *O. similis* (Fig. 16).

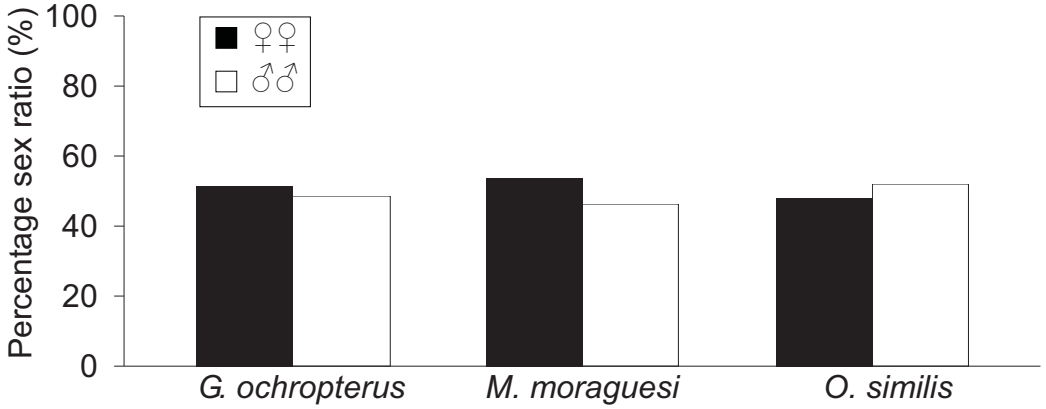

Fig. 16: Percentage portion of sexes of *Geocoris ochropterus*, *Montandoniola moraguesi*, and *Orius similis* with mixed population of *Thrips tabaci* as prey on cucumber leaves at temperature 25±1°C

Longevity

Fig. 17 presents the longevities of adult females and males of *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula*.

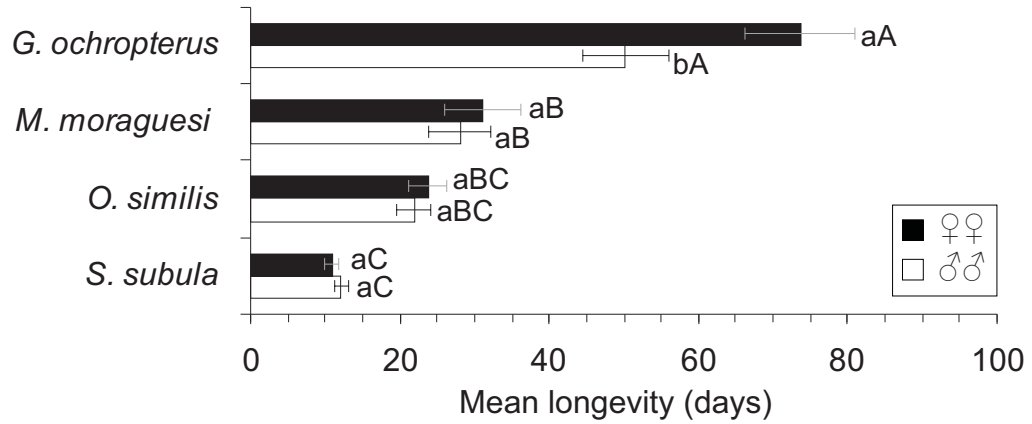

Fig. 17: Mean longevity of adult females and males of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with mixed population of *Thrips tabaci* as prey on cucumber leaves at temperature 25±1°C. [Bars with different small letters indicate significant differences between the female and male within the same predatory species, while bars with different capital letters indicate significant differences among different predatory species within the same sex at p≤5% (two-factor ANOVA)].

Adult *G. ochropterus* lived with a mean longevity of 73.7 days for females and 50.2 days for males, significantly longest among the tested predatory species. No significant differences were recorded in the longevities between *M. moraguesi* (31.1 days for females and 28.1 days for males) and *O. similis* (23.8 days for females and 21.9 days for males). The longevity of *S. subula* was 10.9 days for females and 12.1 days for males, significantly shorter than those of *M. moraguesi*, but similar to those of *O. similis*.

Fecundity

With *T. tabaci* as prey, the predatory species were observed in terms of the periods of pre-oviposition, oviposition and post-oviposition. At the same time, the daily fecundity was noted over the whole oviposition period.

Oviposition period

At 25±1°C temperature, the mean pre-oviposition periods of *G. ochropterus* (7.7 days) and *S. subula* (7.8 days) were similar (Tab. 6). They were significantly longer than those of *M. moraguesi* (5.1 days) and *O. similes* (4.3 days).

Tab. 6: Mean periods of pre-oviposition, oviposition and post-oviposition of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with mixed population of *Thrips tabaci* as prey on cucumber leaves at temperature 25±1°C.

Predator species	n	Period of (days)					
		Pre-oviposition		Oviposition		Post-oviposition	
		Mean±SE	Min.-Max.	Mean±SE	Min.-Max.	Mean±SE	Min.-Max.
G. ochropterus	10	7.7±0.2 a	7 – 9	66.2±6.6 a	19 – 80	3.9±1.2 a	0 – 11
M. moraguesi	10	5.1±0.2 b	4 – 6	25.9±3.5 b	6 – 41	2.4±0.8 a	0 – 6
O. similis	10	4.3±0.1 c	4 – 5	16.8±2.1 bc	2 – 23	2.2±0.9 a	0 – 8
S. subula	10	7.8±0.2 a	7 – 9	4.0±0.9 c	1 – 9	1.2±0.7 a	0 – 6

Means in columns with different letters indicate significant differences among the predator species at P≤5% (one-factor ANOVA).

Among the tested predatory species, the mean oviposition period was significantly longest in *G. ochropterus* with 66.2 days, and shortest in *S. subula* with 4.0 days. It was similar between *M. moraguesi* (25.9 days) and *O. similis* (16.8 days). The post-oviposition periods were not significantly different among the four tested predatory species, ranging from 0 to 11 days.

Daily and total fecundity

As shown in Fig. 18, *G. ochropterus* females started to lay eggs with a mean of 0.4 eggs/♀ on 8th day after adult emergence. Its daily fecundity then fluctuated with a maximum of 4.1 eggs/♀ on 41st day. The females stopped oviposition within 90 days after adult emergence. *M. moraguesi* females started to oviposit with a mean of 0.1 eggs/♀on 5th day. Afterwards, the mean number of its daily laid eggs fluctuated during the oviposition period, and reached a maximum of 3.2 eggs/♀ on the 12th day. Oviposition of *O. similis* females was started with a mean of 2.7 eggs/♀ on 5th day, and stopped on 27th day. The mean number of eggs daily laid by *O. similis* varied on different days, and reached a maximum of 6.8 eggs/♀ on 10th day. *S. subula* started oviposition with a mean of 0.3 eggs/♀ on 8th day, and produced a maximum of 0.9 eggs/♀ on 10th day. It then stopped oviposition on 18th day.

Over the entire longevity, *G. ochropterus* laid a mean total fecundity of 145.4 eggs/♀. It was significantly higher than the other 3 predatory species. The total eggs laid by *M. moraguesi* and *O. similis* over entire longevity were not significantly different with a mean of 56.2 and 60.0 eggs/♀, respectively. *S. subula* laid the lowest mean total fecundity among the four tested predatory bug species with a mean of 3.0 eggs/♀.

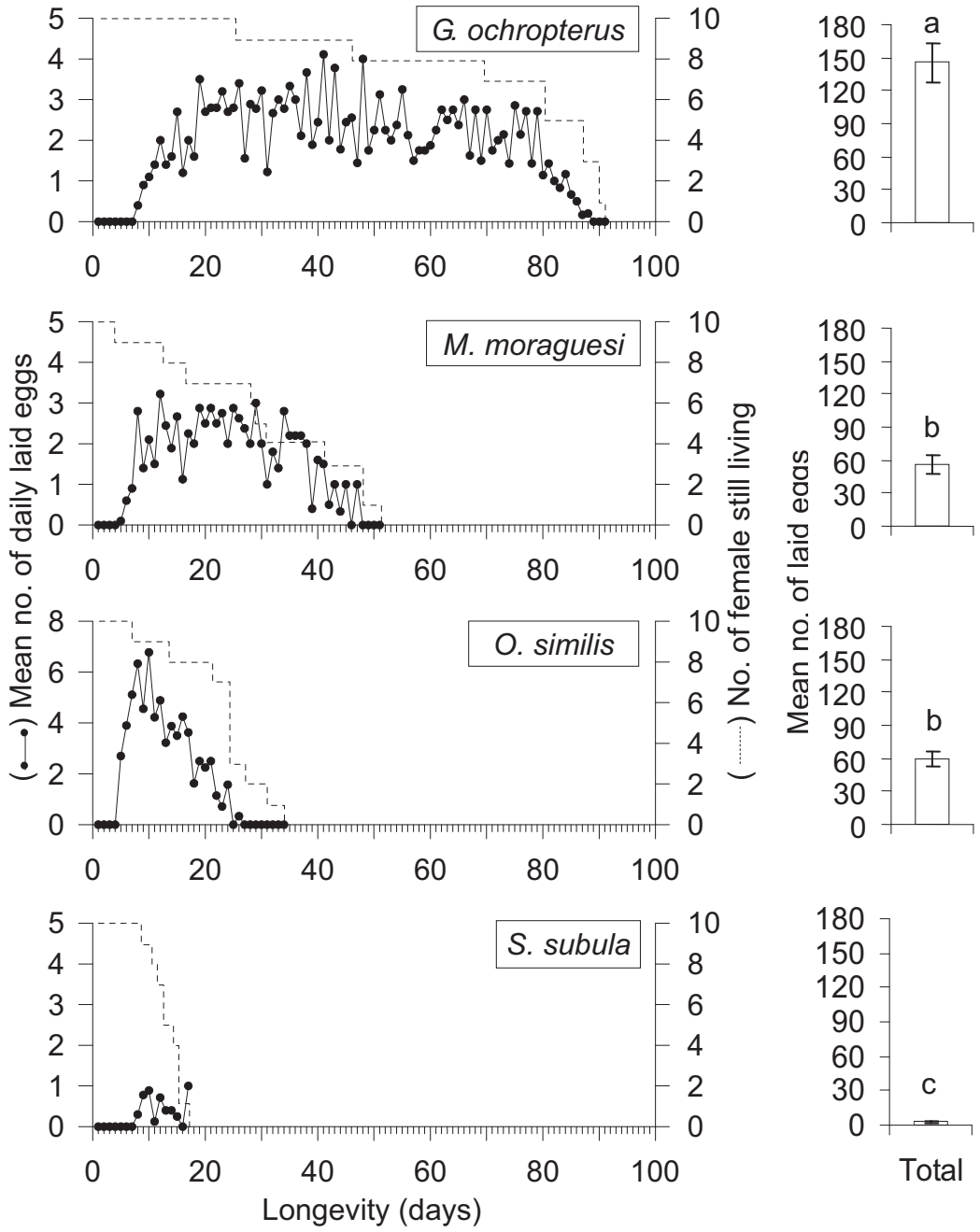

Fig. 18: Mean number of daily laid eggs by *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with on mixed population of *Thrips tabaci* as prey on cucumber leaves at temperature 25±1°C. [Bars with small letters indicate significant difference among predatory species at p≤5% (one-factor ANOVA)]

3.1.1.2.2 Prey consumption

The present experiment were here carried out to determine the daily prey consumptions by the four predatory bug species throughout their entire nymphal development as well as the first 15 days after the emergence of their adult females and males. In the experiments, L_2 *T. tabaci* were offered as prey on cucumber leaf discs at 25±1°C temperature, relative humidity of 60±10% as well as a photoperiod of 16:8h (L:D) under laboratory conditions.

Prey consumption by nymphal predators

During the nymphal development, *G. ochropterus* nymphs consumed a mean of 1.6 thrips on 1st day after hatching (Fig. 19). Its daily prey consumption increased gradually to reach a peak of 17.9 thrips by N_5 instar on 34st day after hatching. Mean daily consumption by *M. moraguesi* nymphs was 1.1 thrips on 1st day, and reached a peak of 9.3 thrips by N_4 instar on 12th day. With *O. similis* nymphs as predators, the mean daily prey consumption was 1.9 thrips on 1st day after hatching, and increased to a maximum of 9.8 thrips by N_5 instar on 14th day. *S. subula* nymphs consumed a minimum of 3.8 thrips by N_1 instar on 1st day after hatching. Its daily prey consumption increased gradually, and reached a maximum of 14.8 thrips by N_4 instar on 38th day after hatching. After growing into N_5 instar, daily prey consumption by *S. subula* nymphs reduced until all nymphs died before adult emergence.

The daily prey consumption during the whole nymphal development was averaged 9.3, 4.9 and 4.8 thrips for *G. ochropterus*, *M. moraguesi* and *O. similis*, respectively. *G. ochropterus* nymphs daily consumed significantly more thrips than *M. moraguesi* and *O. similis* did. No significant difference of the daily prey consumption was recorded between *M. moraguesi* and *O. similis*. The daily prey consumption by *S. subula* nymphs was averaged 9.2 thrips during the successful instars (N_1-N_4). It was similar to that of *G. ochropterus* nymphs. But *S. subula* nymphs reduced the daily consumption dramatically in N_5 instar, and all died before adult emergence.

During the entire nymphal development, *G. ochropterus* killed a mean total of 329.6 thrips/ predator, significantly higher than *M. moraguesi* (90.0 thrips) and *O. similis* (65.9 thrips).

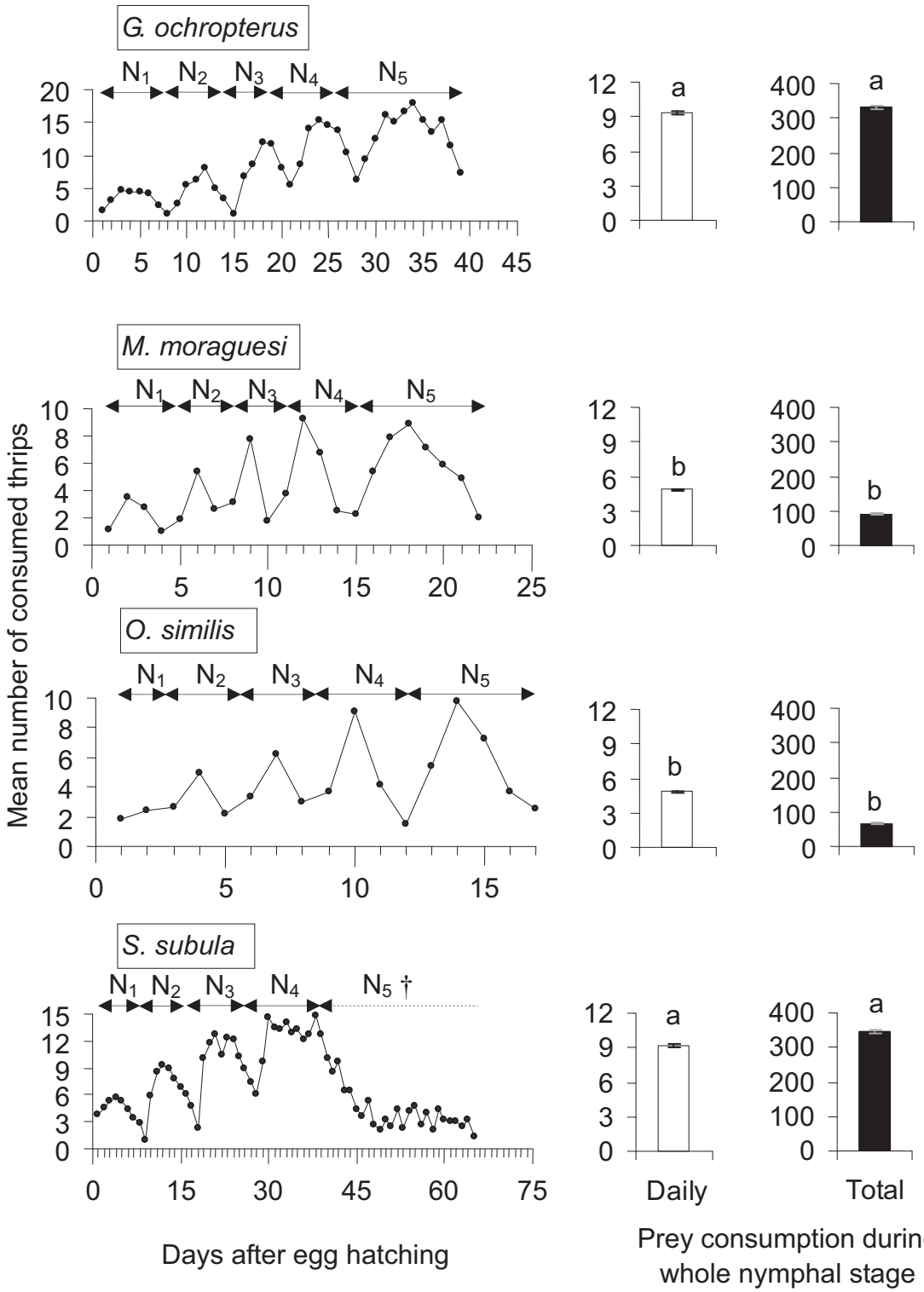

Fig. 19: Mean daily and total prey consumption by nymphs of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* during development with L_2 *Thrips tabaci* on cucumber leaves at temperature 25±1°C. [Bars with different letters indicate significant differences among different predatory species at p≤5% (one-factor ANOVA)]

Prey consumption by adult predators

Fig. 20 indicates the prey consumption by the adult females and males of the four predatory species with L_2 *T. tabaci* as prey at 25±1°C. Adult *G. ochropterus* consumed a mean of 4.8 thrips/♀ or 6.0 thrips/♂ on the 1st day after adult emergence. Afterward, its mean daily prey consumption fluctuated with a maximum of 27.3 thrips/♀ on the 13th day or 20.0 thrips/♂ on the 7th day. With adult *M. moraguesi* as a predator, the mean daily prey consumption was 2.1 thrips/♀ and 2.4 thrips/♂ on the 1st day. And then, the prey consumption varied on different days with a maximum of 5.3 thrips/♀ or 4.4 thrips/♂ on the 8th and 10th days, respectively. On 1st day, adult *O. similis* consumed a mean of 1.3 thrips/♀ or 0.8 thrips/♂. Its daily prey consumption was then in a dynamic number with a maximum of 4.7 thrips/♀ on the 7th day or 3.7 thrips/♂ on the 10th day. Adult *S. subula* started predation with a mean daily consumption of 0.7 thrips for both sexes on the 1st day. Its maximum daily prey consumption was a mean of 1.6 thrips/♀ on the 13th day or 1.1 thrips/♂ on 8th day.

When data were pooled over the whole 15-day period after adult emergence, the daily prey consumption was averaged 17.1 thrips/♀ and 15.8 thrips/♂ for *G. ochropterus*, 3.9 thrips/♀ and 3.1 thrips/♂ for *M. moraguesi*, 3.4 thrips/♀ and 2.8 thrips/♂ for *O. similis*, as well as 0.8 thrips/♀ and 0.7 thrips/♂ for *S. subula*. On the basis of the daily prey consumption within same predator sex, adult *G. ochropterus* displayed significantly higher predation efficiency than the other 3 predatory species. Predation efficiency of *M. moraguesi* was similar to that of *O. similis* within same sex. The efficiency of *S. subula* was significantly lower than the other predatory species.

Over the 15-day-period, the number of thrips consumed by adult *G. ochropterus* was totaled a mean of 243.5 thrips/♀ and 202.1 thrips/♂. The total number of consumed thrips was 51.0 thrips/♀, 41.2 thrips/♂ for adult *M. moraguesi*, and 47.7 thrips/♀, 35.2 thrips/♂ for *O. similis*, as well as 9.6 thrips/ ♀, 7.9 thrips/ ♂ for *S. subula*. The mean total prey consumption by adult *G. ochropterus* was significantly higher than those of the other 3 predatory species within same predator sex. The consumption was similar between *M. moraguesi* and *O. similis* within same

sex. *S. subula* displayed the lowest total prey consumption among the tested predatory species, but not significantly different from the total prey consumption of *O. similis* within same sexes.

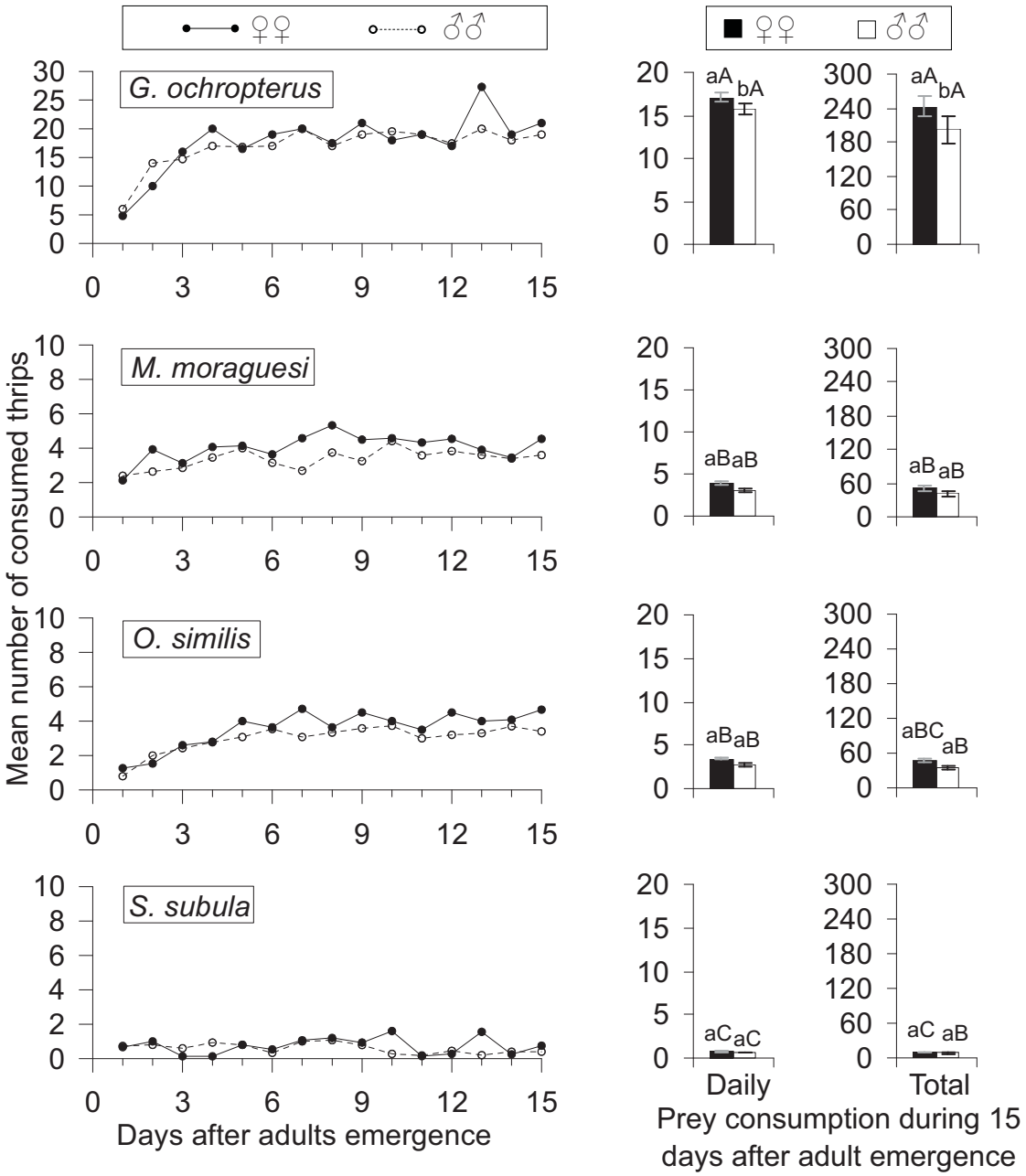

Fig. 20: Mean daily and total prey consumption by adults of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with L_2 *Thrips tabaci* as prey on cucumber leaves at temperature 25±1°C. [Bars with different small letters indicate significant differences between the female and male within the same predatory species. Bars with different capital letters indicate significant differences among different predatory species within the same sex at $p \leq 5\%$ (two-factor ANOVA)]

3.1.1.3 With *Gynaikothrips ficorum* as prey

Experiments have been carried out to investigate on the biology and prey consumption of *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula* with *G. ficorum* as prey on leaves of Banyan trees.

3.1.1.3.1 Biology

The biology of the four predatory species was investigated on the characteristics such as embryonic and nymphal development, mortality, sex ratio, longevity as well as fecundity.

Embryonic development

The mean period for embryonic development was 15.9 days for *G. ochropterus*, 5.4 days for *M. moraguesi*, 3.3 days for *O. similis*, and 11.3 days for *S. subula* (Tab.7). It was significantly longer for *G. ochropterus* than for the other 3 predatory species. *S. subula* took the second longest period to complete the embryonic development. The embryonic development of *M. moraguesi* was significantly slower than that of *O. similis*.

Tab. 7: Mean embryonic developmental period of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis*, and *Scipinia subula* on leaves of *Ficus microcarpa* at 25±1°C temperature

Predatory species	n	Embryonic developmental period (days)	
		Mean±SE	Min. - Max.
G. ochropterus	20	15.9±0.2 d	15 - 17
M. moraguesi	20	5.4±0.1 b	5 - 6
O. similis	20	3.3±0.1 a	3 - 4
S. subula	20	11.3±0.1 c	11 - 12

Means in columns followed by different letters are significantly different at p≤1% (one-factor ANOVA).

Nynphal development

The mean periods for nymphal development of the four predatory bug species were listed in Table 8. *S. subula* did not develop further after they reached N_5 instar. The other three predatory

bug species completed nymphal development with significantly different total periods from N_1 instar to adult emergence. The total developmental period was averaged 34.9 days for *G. ochropterus*, longer than those of *M. moraguesi* (18.5 days) and *O. similis* (11.9 days). Without regarding *S. subula*, N_5 instar developed significantly slower than other instars within same predatory species.

Tab. 8: Mean nymphal developmental period of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with L_2 *Gynaikothrips ficorum* as prey on leaves of *Ficus microcarpa* at temperature 25±1°C

Predatory species	n	Developmental period (days)					Total (N_1 to adult) (days) Mean±SE
		N_1 Mean±SE	N_2 Mean±SE	N_3 Mean±SE	N_4 Mean±SE	N_5 Mean±SE	
G. ochropterus	20	7.6±0.1 bA	5.7±0.1 c B	5.5±0.1 c B	5.9±0.1 cB	10.2±0.2 aA	34.9±0.3 A
M. moraguesi	20	3.2±0.1 cB	2.6±0.1 cdC	2.5±0.1 d C	4.1±0.2 bC	6.2±0.2 aB	18.5±0.4 B
O. similis	20	1.8±0.1 cC	1.8±0.2 c D	2.2±0.1 bcC	2.6±0.1 bD	3.5±0.1 aC	11.9±0.3 C
S. subula	20	7.2±0.2 bA	7.0±0.3 b A	7.3±0.2 b A	14.7±0.5 aA	†	

Means in columns with different small letters indicate significant differences among different instars within the same predatory species, while the means with different capital letters indicate significant differences among different predatory species within the same instars at $p \leq 5\%$ (two-factor ANOVA)

Mortality

Fig. 21 indicates the mortality of the tested predatory species during immature development.

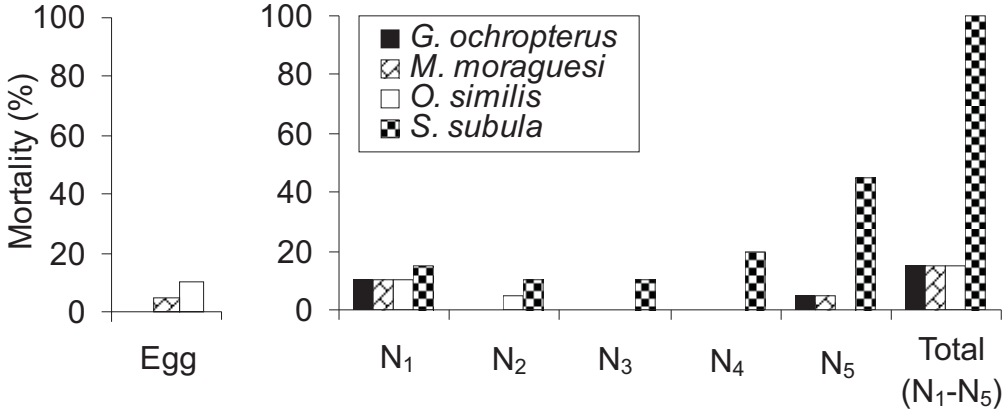

Fig. 21: Percentage mortality of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* during embryonic and nymphal development with L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 25±1°C

Mortality of eggs only occurred during the embryonic development of *O. similis* with 10% and *M. moraguesi* with 5%. Except for *S. subula* which could not survive by feeding on *G. ficorum* as prey, the total mortality from N_1 to adult emergence for the other three predatory bug species was less than 15%. Most mortality of nymphs occurred in N_4-N_5 instars for *S. subula*, while it was higher in N_1 istar than in other instars of the other 3 predatory species.

Sex ratio

As shown in Fig. 22, among the progeny of the predatory species with *G. ficorum* as prey, percentage portion of females was 54.9% (♀♀) for *G. ochropterus*, 51.9% (♀♀) for *M. moraguesi* and 50.8% (♀♀) for *O. similis*.

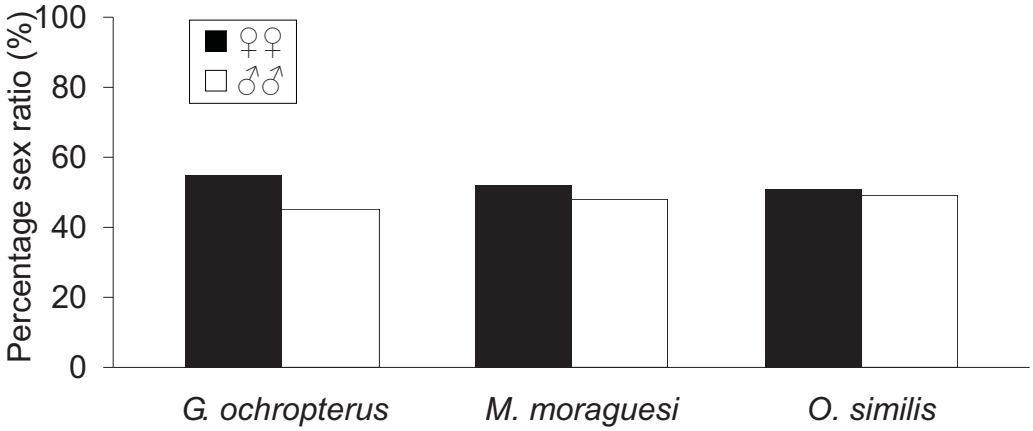

Fig. 22: Percentage portion of sexes of *Geocoris ochropterus*, *Montandoniola moraguesi* and *Orius similis* with mixed population of *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 25±1°C

Longevity

With *G. ficorum* as prey, the mean longevity was 75.0 and 54.0 days for adult females and males of *G. ochropterus*, respectively (Fig. 23). It was significantly longer than those of the other predatory bug species tested here. Adult females of *M. moraguesi* lived a mean of 35.8 days, significantly longer than adult females of *O. similis* (22.5 days). The mean longevity of *M. moraguesi* males was 27.3 days, similar to that of *O. similis* males (20.0 days). *S. subula* adults

showed a mean longevity of 11.0 (♀♀) and 10.4 (♂♂) days, not significantly different from those of *O. similis*.

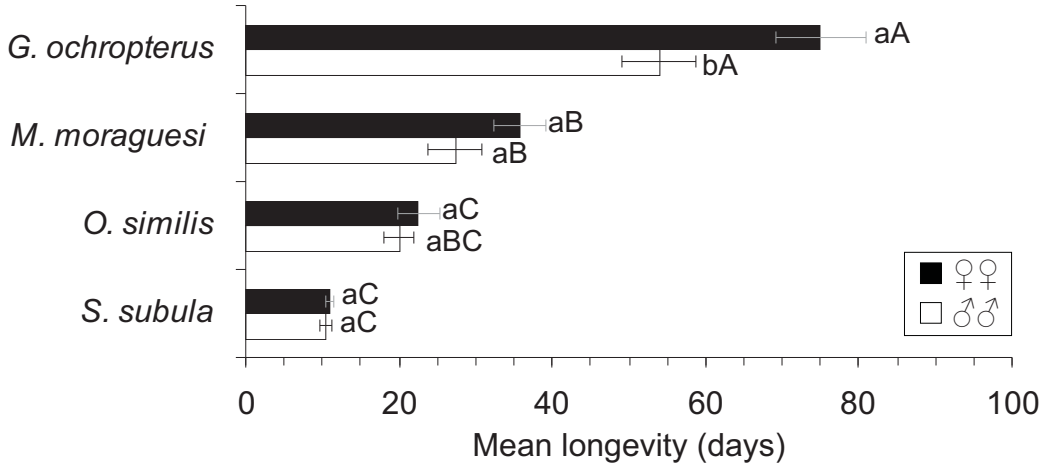

Fig. 23: Mean longevity of adult females and males of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with mixed population of *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 25±1°C. [Bars with different small letters indicate significant differences between the female and male within the same predatory species, while bars with different capital letters indicate significant differences among different predatory species within the same sex at p≤5% (two-factor ANONA)]

Fecundity

The experiment was conducted on the pre-oviposition, ovioposition and post-oviposition periods, as well as the fecundity of the tested predatory species.

Oviposition period

Tab. 9 lists the periods of pre-oviposition, ovioposition and post-oviposition of predatory species with *G. ficorum* as prey. Adult females of *O. similis* exhibited a significantly shorter pre-oviposition period, with a mean of 4.4 days, than the other 3 predatory species. The period of pre-oviposition was not significantly different among *G. ochropterus*, *M. moraguesi* and *S. subula* with a mean of 7.0, 5.3 and 6.7 days, respectively. The oviposition period of *G.*

ochropterus lasted a mean of 64.4 days. It was significantly longer than those of *M. moraguesi* (23.3 days), *O. similis* (18.1 days) and *S. subula* (3.8 days). The four predatory species was not significantly different from each other in terms of the post-oviposition period (0-12 days).

Tab. 9: Mean periods of pre-oviposition, oviposition and post-oviposition of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with mixed population of *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 25±1°C.

Predator species	n	Period of (days)					
		Pre-oviposition		Oviposition		Post-oviposition	
		Mean±SE	Min.-Max.	Mean±SE	Min.-Max.	Mean±SE	Min.-Max.
G. ochropterus	10	7.0±0.3 a	5 - 8	64.4±5.1 a	32 - 76	4.1±1.0 a	0 - 11
M. moraguesi	10	5.3±0.3 a	4 - 7	23.3±2.8 b	5 - 31	6.8±1.2 a	0 - 12
O. similis	10	4.4±0.2 b	4 - 6	18.1±2.4 bc	5 - 29	2.3±0.9 a	0 - 7
S. subula	10	6.7±0.3 a	5 - 9	3.8±0.9 c	1 - 9	1.4±0.5 a	0 - 5

Means in columns with different letters indicate significant differences among the predator species at P≤5% (one-factor ANOVA).

Daily and total fecundity

The oviposition of the predatory species started with a mean daily fecundity of 0.1, 0.7, 3.6 and 0.1 eggs/♀ for *G. ochropterus* on 6th day, *M. moraguesi* on 5th day, *O. similis* on 6th day and *S. subula* on 6th day after adult emergence, respectively (Fig. 24). From then on, all the tested predatory species daily laid eggs in a fluctuating number during their own oviposition periods. The maximum daily fecundity of *G. ochropterus* was a mean of 4.6 eggs/♀ on 25th day. The maximum of *M. moraguesi*, *O. similis* and *S. subula* was a mean of 7.0, 7.3, and 0.9 eggs/♀ on the 8, 12 and 8th day, respectively.

G. ochropterus produced a mean total fecundity of 154.4 eggs/♀ over the whole longevity. The mean total fecundity of *M. moraguesi* was 99.8 eggs/♀, which was significantly lower than that of *G. ochropterus*, but higher than that of *O. similis* (65.8 eggs/♀). *S. subula* was recorded the lowest total fecundity among the tested predatory species with a mean of 2.2 eggs/♀.

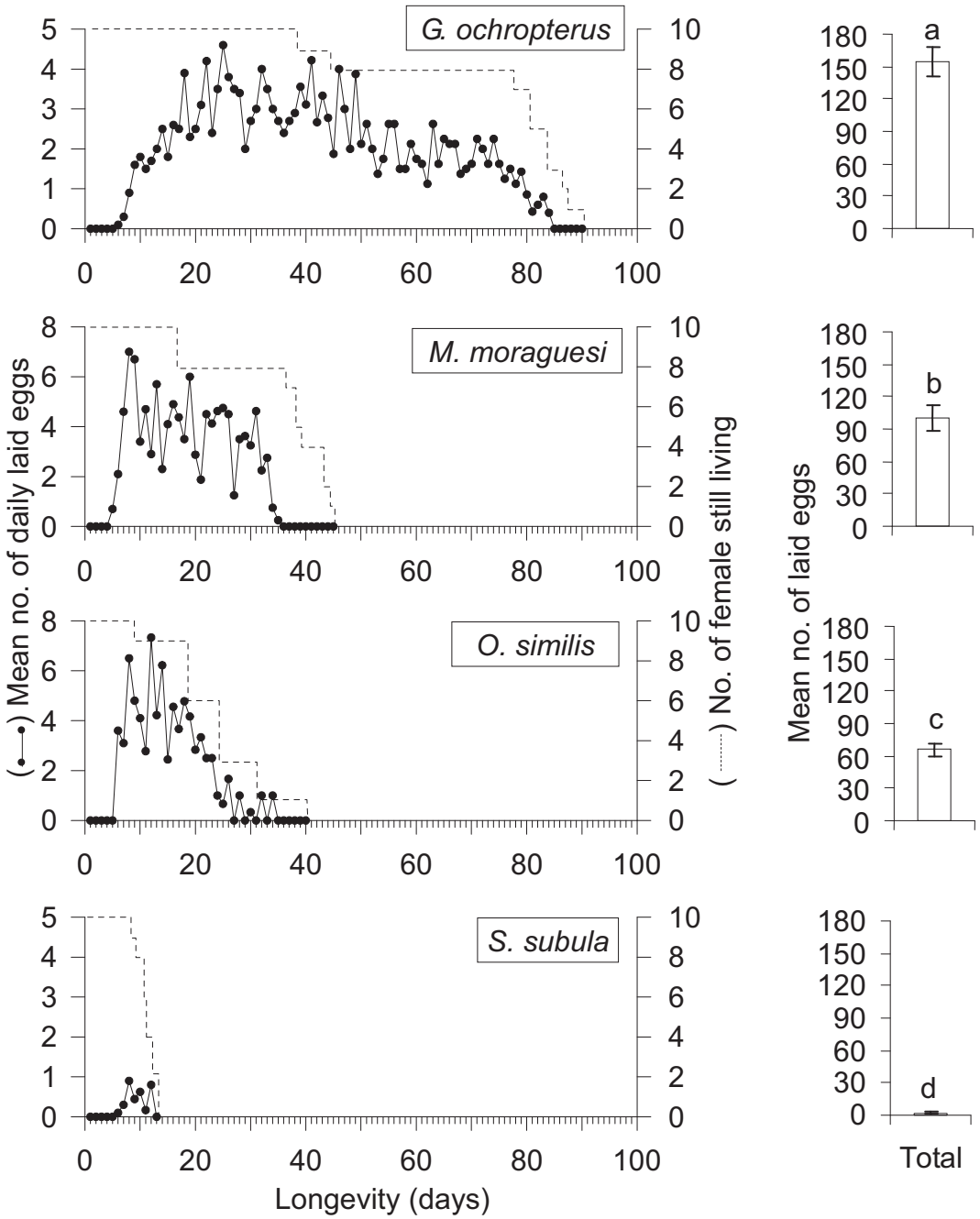

Fig. 24: Mean number of daily laid eggs by *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with mixed population of *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 25±1°C. [Bars with small letters indicate significant difference among different predatory species at p≤5% (one-factor ANOVA)]

3.1.1.3.2 Prey consumption

With L_2 *G. ficorum* as prey on leaves of *F. microcarpa*, the four predatory bug species were studied on the prey consumption by the nymphs throughout the entire development and by the adults over the first 15 days after the emergence. The experiment was conducted at temperature 25±1°C, relative humidity of 60±10% as well as a photoperiod of 16:8h (L:D).

Prey consumption by nymphal predators

Fig. 25 illustrates the prey consumption by *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula*. The mean daily prey consumption by *G. ochropterus* was 0.5 thrips on the 1st day after hatching, and increased gradually with the instars of predatory nymphs. It reached a maximum of 7.4 thrips on the 34th day. *M. moraguesi* nymphs started the predation with a mean of 0.7 thrips on the 1st day, and daily consumed a maximum of 3.3 thrips by N_4 nymphs on the 12th day and N_5 nymphs on the 19th day. For *O. similis* nymphs, the daily prey consumption was a mean of 0.9 thrips on the 1st day, and increased to a maximum of 3.5 thrips by N_5 nymphs on the 13th day. Starting the predation with a mean consumption of 1.1 thrips on the 1st day, *S. subula* daily consumed more thrips as the instars increase until it developed into N_5 nymphs. *S. subula* reduced the prey consumption during N_5 instar, and all nymphs died before adult emergence.

When data were pooled over the whole nymphal development, the daily prey consumption of *G. ochropterus* was averaged 2.9 thrips. It was significantly higher than the daily prey consumption of *M. moraguesi* (2.3 thrips) and *O. similis* (1.8 thrips).

G. ochropterus consumed a mean total number of 102.9 thrips throughout the nymphal development. It consumed significantly more thrips than *M. moraguesi* and *O. similis* did. The total prey consumptions of *M. moraguesi* and *O. similis* were similar with a mean of 35.7 and 20.5 thrips, respectively.

S. subula consumed considerable high daily and total prey consumption in its first 4 instars. However, the predatory bugs of N_5 instar failed to feed on *G. ficorum* and all died before adult emergence.

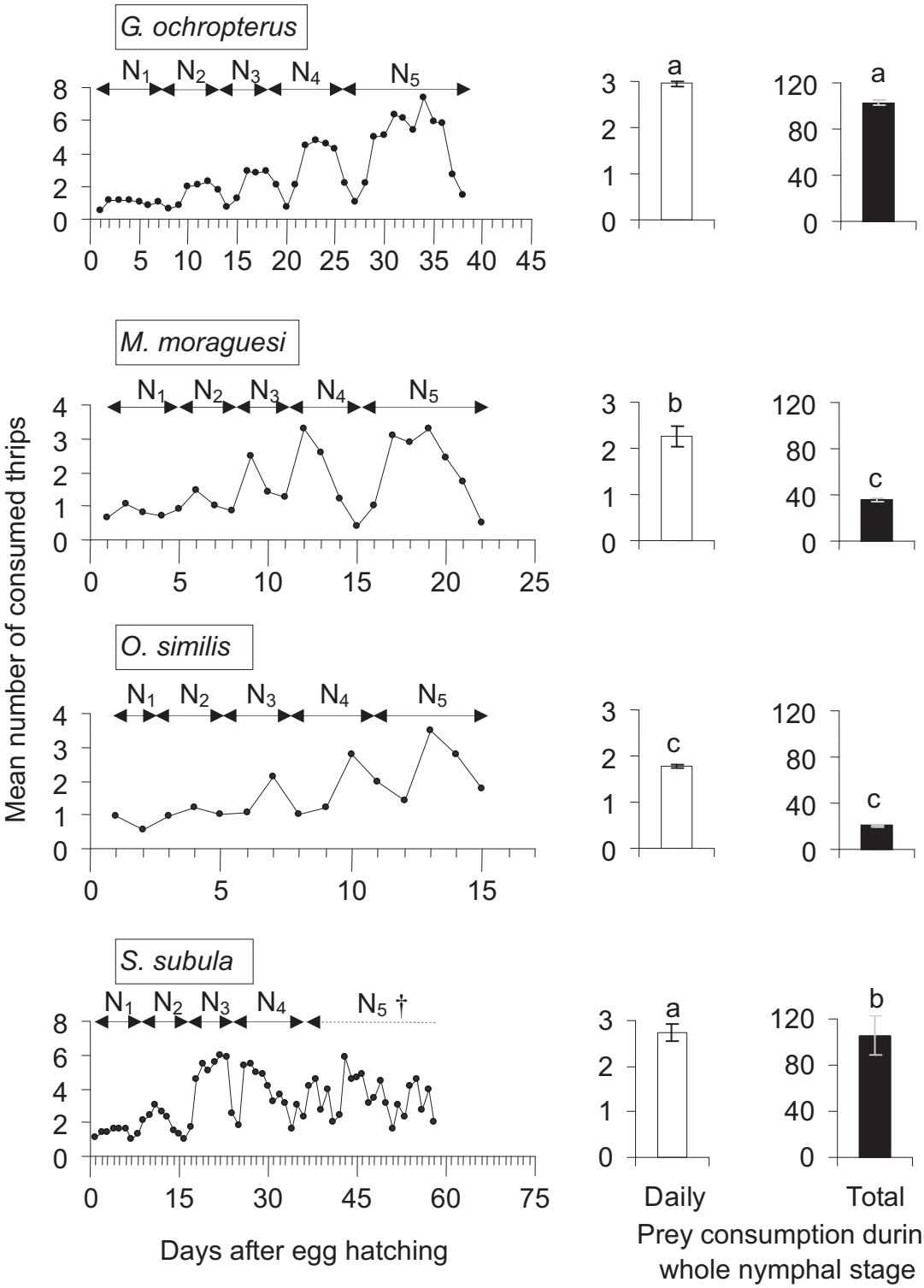

Fig. 25: Mean daily and total prey consumption by nymphs of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 25±1°C. [Bars with different letters indicate significant differences among different predatory species at p≤5% (one-factor ANOVA)]

Prey consumption by adult predators

The prey consumption by the predatory adults is shown in Fig. 26.

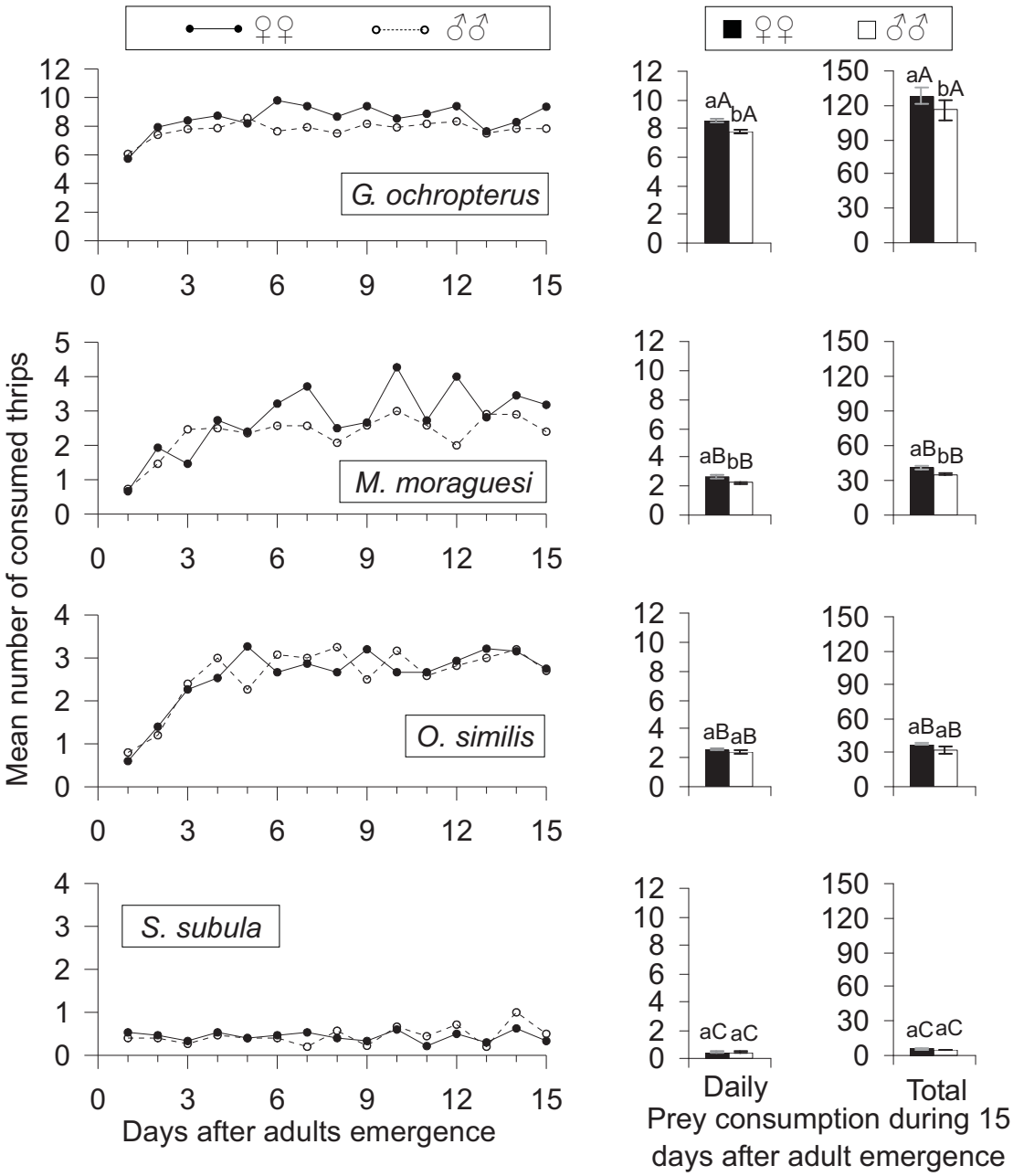

Fig. 26: Mean daily and total prey consumption by adults of *Geocoris ochropterus*, *Montandoniola moraguesi*, *Orius similis* and *Scipinia subula* with L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 25±1°C. [Bars with different small letters indicate significant differences between the female and male within the same predatory species. Bars with different capital letters indicate significant differences among different predatory species within the same sex at $p \leq 5\%$ (two-factor ANOVA)]

By feeding on L_2 *G. ficorum* as prey, the predatory adults started predation on the 1st day with a mean of 5.7 thrips/♀ and 6.1 thrips/♂ for *G. ochropterus*, 0.7 thrips/♀ and 0.7 thrips/♂ for *M. moraguesi*, 0.6 thrips/♀ and 0.8 thrips/♂ for *O. similis*, as well as 0.5 thrips/♀ and 0.4 thrips/♂ for *S. subula*. From then on, *G. ochropterus* daily consumed 7.6-9.8 thrips /♀, and 7.4-8.6 thrips /♂. *M. moraguesi* daily consumed 1.5-4.3 thrips/♀, and 1.5-3.0 thrips/♂. The mean daily prey consumption by *O. similis* was 1.4-3.3 thrips/♀, and 1.2-3.3 thrips/♂. For *S. subula*, it was 0.2-0.6 thrips/♀, and 0.2-1.0 thrips/♂.

During the first 15 days after adult emergence, the number of thrips daily consumed by *G. ochropterus* was a mean of 8.6 thrips/♀ or 7.7 thrips/♂. It was significantly higher than those of *M. moraguesi* (2.6 thrips/♀, 2.2 thrips/♂) and *O. similis* (2.6 thrips/♀, 2.4 thrips/♂). Among the tested predatory species, *S. subula* daily consumed the significantly lowest number of thrips with a mean of 0.4 thrips for adults of both sexes.

Over the 15-day-period after the predatory adult emergence, the mean total prey consumption by *G. ochropterus* was 128.2 thrips/♀ and 116.1 thrips/♂. It was significantly higher than that of *M. moraguesi* (41.5 thrips/♀, 35.4 thrips/♂) and *O. similis* (37.7 thrips/♀, 32.3 thrips/♂). The total prey consumption of *S.subula* was the significantly lowest among the four predatory species with a mean of 5.9 thrips/ ♀ and 4.7 thrips/ ♂.

By feeding on L_2 *G. ficorum* as prey, the predatory adults started predation on the 1st day with a mean of 5.7 thrips/♀ and 6.1 thrips/♂ for *G. ochropterus*, 0.7 thrips/♀ and 0.7 thrips/♂ for *M. moraguesi*, 0.6 thrips/♀ and 0.8 thrips/♂ for *O. similis*, as well as 0.5 thrips/♀ and 0.4 thrips/♂ for *S. subula*. From then on, *G. ochropterus* daily consumed 7.6-9.8 thrips /♀, and 7.4-8.6 thrips /♂. *M. moraguesi* daily consumed 1.5-4.3 thrips/♀, and 1.5-3.0 thrips/♂. The mean daily prey consumption by *O. similis* was 1.4-3.3 thrips/♀, and 1.2-3.3 thrips/♂. For *S. subula*, it was 0.2-0.6 thrips/♀, and 0.2-1.0 thrips/♂.

During the first 15 days after adult emergence, the number of thrips daily consumed by *G. ochropterus* was a mean of 8.6 thrips/♀ or 7.7 thrips/♂. It was significantly higher than those of *M. moraguesi* (2.6 thrips/♀, 2.2 thrips/♂) and *O. similis* (2.6 thrips/♀, 2.4 thrips/♂). Among the

tested predatory species, *S. subula* daily consumed the significantly lowest number of thrips with a mean of 0.4 thrips for adults of both sexes.

Over the 15-day-period after the predatory adult emergence, the mean total prey consumption by *G. ochropterus* was 128.2 thrips/♀ and 116.1 thrips/♂. It was significantly higher than that of *M. moraguesi* (41.5 thrips/♀, 35.4 thrips/♂) and *O. similis* (37.7 thrips/♀, 32.3 thrips/♂). The total prey consumption of *S.subula* was the significantly lowest among the four predatory species with a mean of 5.9 thrips/ ♀ and 4.7 thrips/ ♂.

3.1.2 Biology of the selected predator *Geocoris ochropterus* at temperature 18 and 30 °C

Based on the investigation of the biology, *G. ochropterus* is superior over *M. moraguesi*, *O. similis* and *S. subula* in terms of longevity, fecundity and prey consumption. Therefore, it was selected for further study. In this section, the experiments were carried out to study on the developmental period, mortality, sex ratio, longevity and fecundity with *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey at 18 and 30±1°C temperature, 60±10% RH and 16: 8 h (L:D).

3.1.2.1 With *Frankliniella occidentalis* as prey

Development

The embryonic and nymphal developments of *G. ochropterus* were determined at 18 and 30±1°C temperatures.

Embryonic development

The embryonic development of *G. ochropterus* was significantly slower at temperature 18°C with a mean period of 42.7 days, than at temperature 30°C with a mean period of 11.6 days (Tab. 10).

Tab. 10: Mean embryonic developmental period of *Geocoris ochropterus* on cucumber leaves at two different temperatures

Temperature (±1°C)	n	Embryonic developmental period (days)	
		Mean±SE	Min. - Max.
18	20	42.7±0.3 b	41 - 44
30	20	11.6±0.1 a	11 - 12

Means in columns with different small letters indicate significant differences at p≤1% (one-factor ANOVA)

Nymphal development

As shown in Tab. 11, the developmental period of each instar reduced significantly with temperature increasing. At 18°C, the period of an instar varied from 12.5 to 27.0 days with L_1 thrips as prey, or from 12.7 to 29.0 days with L_2 thrips. The mean total period from N_1 to adult emergence was 98.5 days with L_1 thrips, or 103.0 days with L_2 thrips. At 30°C, *G. ochropterus* complete an instar development in 5.3-8.2 days with L_1 thrips, or 5.6-7.9 days with L_2 thrips as prey. The mean period for the whole nymphal development of *G. ochropterus* was 30.3 days with L_1 thrips, or 31.4 days with L_2 thrips. Within the same temperatures and predator instars, the prey instars had no significant effect on the developmental period.

Tab. 11: Mean nymphal developmental period of *Geocoris ochropterus* with L_1 and L_2 *Frankliniella occidentalis* as prey on cucumber leaves at different temperatures

Temp. (±1°C)	Prey stage	n	Developmental period (days)					Total (N_1 to adult) (days) Mean±SE
			N_1 Mean±SE	N_2 Mean±SE	N_3 Mean±SE	N_4 Mean±SE	N_5 Mean±SE	
18	L_1	20	17.5±1.4aB	12.5±1.4aB	20.8±1.4aB	21.0±1.6aB	27.0±1.2aB	98.5±1.7aB
	L_2	20	18.3±1.7aB	12.7±1.7aB	21.3±1.5aB	21.7±1.7aB	29.0±1.7aB	103.0±1.5aB
30	L_1	20	6.1±0.2aA	5.4±0.2aA	5.3±0.1aA	5.3±0.1aA	8.2±0.2aA	30.3±0.4aA
	L_2	20	6.0±0.2aA	5.6±0.2aA	6.0±0.3aA	5.7±0.1aA	7.9±0.3aA	31.4±0.6aA

Means in columns with different small letters indicate significant differences between different prey stages within same predator instars and temperatures, the means in columns with different capital letters indicate significant differences between different temperatures within same predator instars at $p \leq 5\%$ (two-factor ANOVA)

Mortality

With L_1 and L_2 *F. occidentalis* as prey, the total mortality of *G. ochropterus* from N_1 instar to adult emergence was 80 and 85% at temperature 18°C, respectively (Fig. 27). At 30°C, the total mortality was 40% with L_1 thrips and 30% with L_2 thrips as prey. The mortality was considerably higher at 18°C than at 30°C. N_1 and N_2 nymphs of *G. ochropterus* were easy to die at the low temperature, in comparison with the other instars.

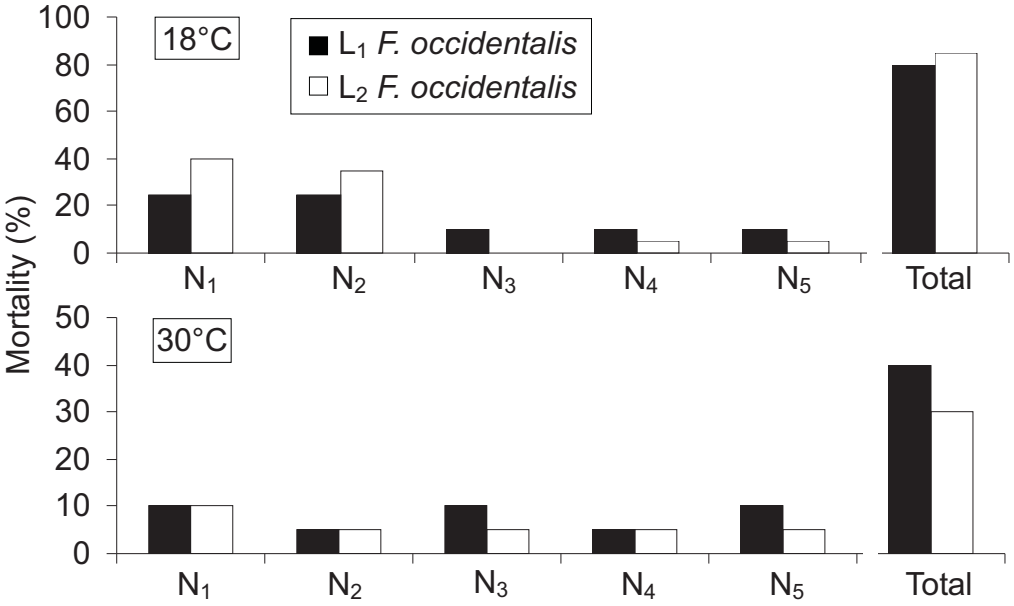

Fig. 27: Percentage mortality of *Geocoris ochropterus* during nymphal development with L_1 and L_2 *Frankliniella occidentalis* as prey on cucumber leaves at temperature 18 and 30±1°C

Sex ratio

Fig. 28 demonstrates the percentage of females of *G. ochropterus* developing at 18 and 30±1°C.

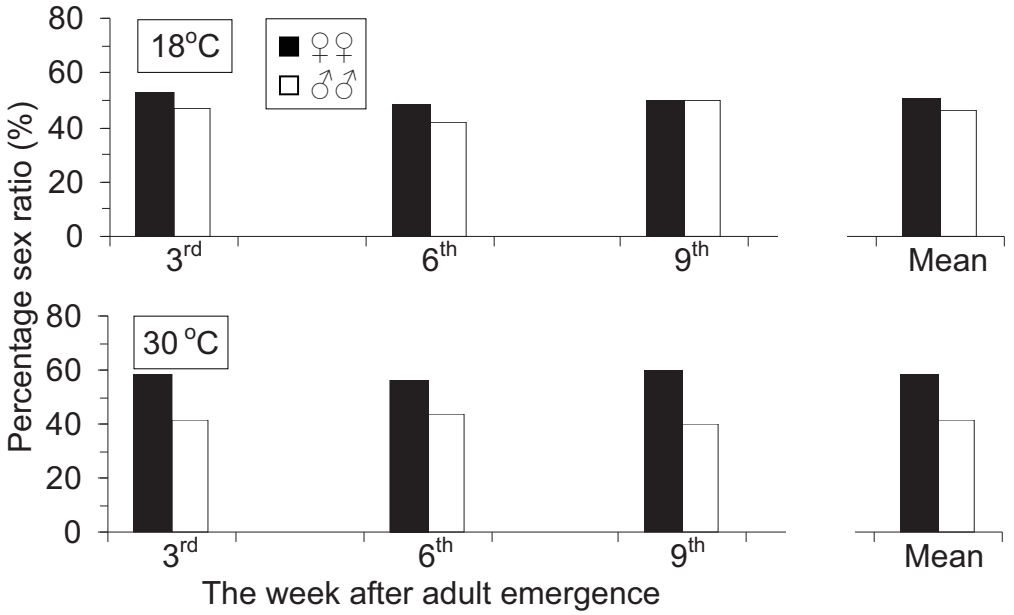

Fig. 28: Weekly summarized percentage sex ratio of *Geocoris ochropterus* by feeding on mixed population of *Frankliniella occidentalis* as prey on cucumber leaves at temperatures 18 and 30±1°C

The eggs of *G. ochropterus*, which were laid within the 3rd, 6th and 9th week after adult emergence at 25°C temperature, were collected and reared to adult stage with mixed population of *F. occidentalis* as prey at temperature 18 and 30°C. As indicated in Fig. 28, by developing at 18°C, the percentage of females was 52.8% for the 3rd week-laid eggs, 48.5% for the 6th week-laid eggs and 50.0% for the 9th week-laid eggs. At 30°C, the percentage of females was 58.3, 56.6 and 59.7% for the eggs laid in the 3rd, 6th and 9th weeks, respectively.

Longevity

At temperature 18°C, the mean longevity of *G. ochropterus* was 59.4 ♀♀, 58.8 ♂♂ days and 66.5 ♀♀, 62.8 ♂♂ days with L_1 and L_2 *F. occidentalis* as prey, respectively (Fig. 29). At temperature 30°C, the mean longevity was 29.7 ♀♀, 28.7 ♂♂ days with L_1 thrips as prey and 29.9 ♀♀, 27.4 ♂♂ days with L_2 thrips. *G. ochropterus* adults lived significantly shorter at 30°C than at 18°C. No significant differences in the longevity were tested between adult females and males within the same prey age and temperature, neither between the two different prey age groups within same predator sex and temperature.

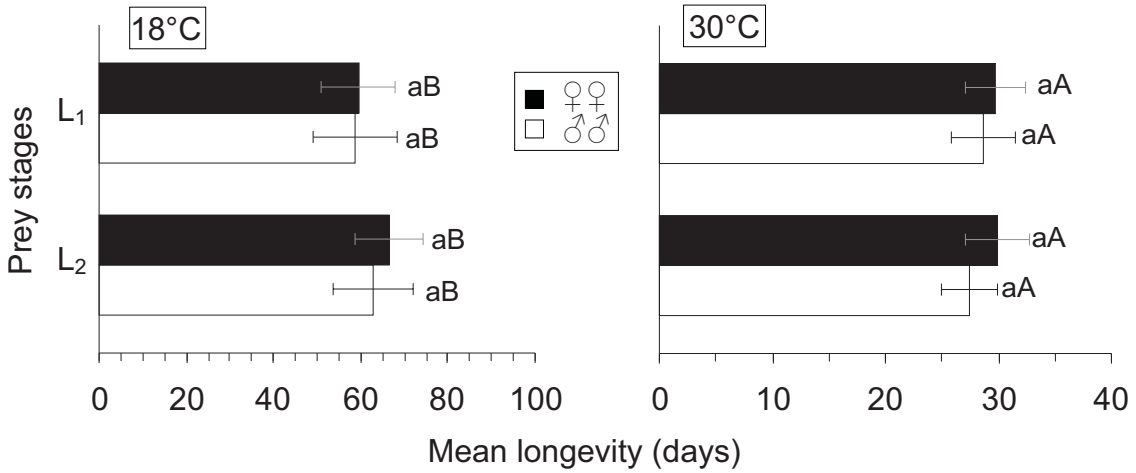

Fig. 29: Mean longevity of adult females and males of *Geocoris ochropterus* with L_1 and L_2 *Frankliniella occidentalis* as prey on cucumber leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the female and male within the same temperature, while bars with different capital letters indicate significant differences between different temperatures within the same prey stages and sex at p≤5% (two-factor ANOVA)]

Fecundity

Adult females of *G. ochropterus* have been observed on their oviposition period, daily and total fecundity during the whole longevity.

Oviposition period

Tab. 12 illustrates the mean periods of pre-oviposition, oviposition and post-oviposition of *G. ochropterus* with mixed population of *F. occidentalis* as prey. The mean pre-oviposition period was significantly longer at temperature 18°C with 33.7 days than at 30°C with 3.8 days. Mean oviposition period was also significantly longer at 18°C with 56.6 days than at 30°C with 20.5 days. Mean period of post-oviposition was significantly shorter at 18°C with 1.7 days than at 30°C with 4.3 days.

Tab.12: Mean periods of pre-oviposition, oviposition and post-oviposition of *Geocoris ochropterus* by feeding on mixed population of *Frankliniella occidentalis* as prey on cumber leaves at different temperatures

Temperature (±1°C)	n	Period of (days)					
		Pre-oviposition		Oviposition		Post-oviposition	
		Mean±SE	Min.-Max.	Mean±SE	Min.-Max.	Mean±SE	Min.-Max.
18	10	33.7±1.4 a	29 - 38	56.6±3.2 a	42 - 67	1.7±0.9 a	0 - 7
30	10	3.8±0.2 b	3 - 5	20.5±2.4 b	6 - 29	4.3±1.5 b	0 - 15

Means in columns with different letters indicate significant differences between the predator species at p≤5% (one-factor ANOVA).

Daily and total fecundity

Figure 30 presents the mean number of daily laid eggs by *G. ochropterus* with mixed population of *F. occidentalis* as prey on cucumber leaves at two temperatures.

At temperature 18°C, the adult females began oviposition on the 29th day after emergence with a mean daily fecundity of 0.3 eggs/♀. The mean daily fecundity fluctuated afterwards and increased to a maximum mean of 2 eggs/♀ on the 98th day. At 30°C, female adult of *G. ochropterus* started oviposition on the 4th day, where the daily fecundity was a mean of 0.6 eggs. The mean number of eggs laid daily by the females increased to a maximum of 7.5 eggs/♀ on 7th

day. Afterwards, the number of daily laid eggs began to decrease in fluctuation until no eggs were laid after the 35th day. As showed in Fig. 30, the mean total number of eggs laid by *G. ochropterus* over its longevity was 12.1 eggs/♀ at 18°C. It was significantly less than that at 30°C temperature, where a mean total number of 67.2 eggs/♀ was recorded.

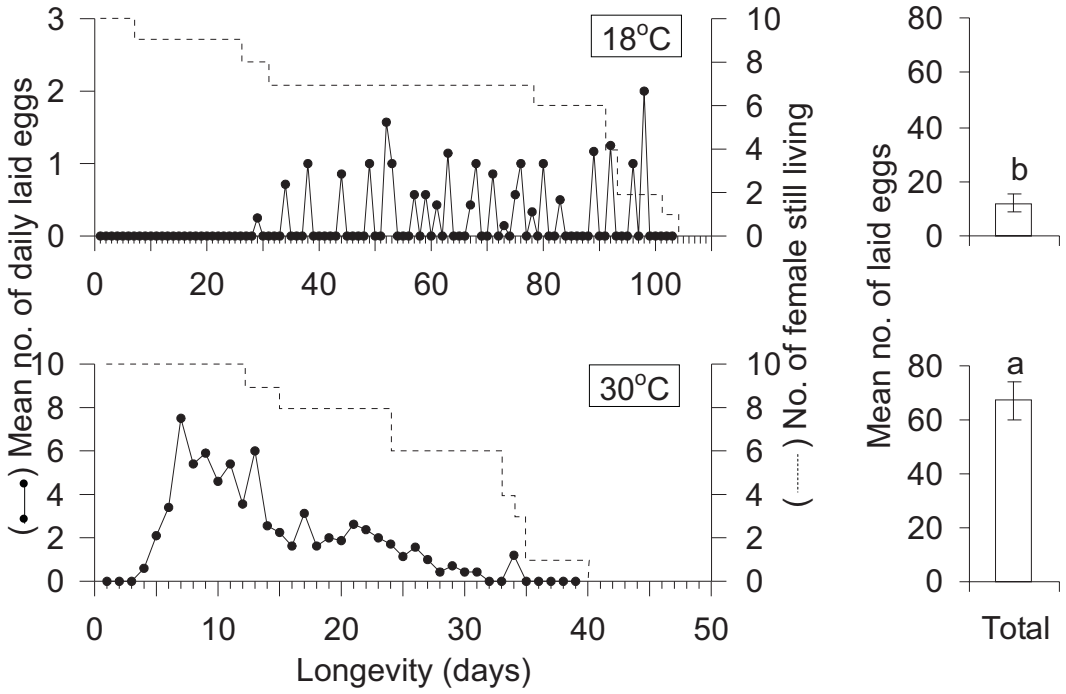

Fig. 30: Mean number of daily ant total laid eggs by *Geocoris ochropterus* females during the oviposition period by feeding on mixed population of *Frankliniella occidentalis* as prey on cucumber leaves at temperature 18 and 30±1°C. [Bars with different letters indicate significant difference between the two temperatures at p≤5% (one-factor ANOVA)]

3.1.2.2 With *Thrips tabaci* as prey

Development

The experiments were carried out to study the embryonic and nymphal developments of *G. ochropterus* with L_1 and L_2 *T. tabaci* as prey on cucumber leaves at temperature 18 and 30±1°C.

Embryonic development

G. ochropterus completed embryonic development in a mean of 41.5 days at temperature 18°C (Tab. 13). At 30°C, the embryonic development was completed in a significantly shorter period with a mean of 11.4 days.

Tab. 13: Mean embryonic developmental period of *Geocoris ochropterus* on cucumber leaves at two different temperatures

Temperature (±1°C)	n	Embryonic developmental period (days)	
		Mean±SE	Min. - Max.
18	20	41.5±0.2 b	40 - 43
30	20	11.4±0.2 a	10 - 13

Means in columns with different small letters indicate significant differences at p≤1% (one-factor ANOVA)

Nymphal development

With *T. tabaci* larvae of different stages as prey, *G. ochropterus* nymphs developed significantly faster as temperature increased from 18 to 30°C (Tab. 14). At temperature 18°C, the nymphs completed an instar in 12.8-27.6 days. The total developmental period form N_1 to adult emergence was a mean of 99.8 day with L_1 thrips as prey, or 102.0 days with L_2 thrips. At 30°C, the developmental period for different instars ranged from 4.6 to 7.7 days. The mean total developmental period at this temperature was 27.7 days with L_1 thrips, or 28.1 days with L_2 thrips. It was significantly shorter than at 18°C. The developmental periods were not significantly different between the two prey stages within the same predator instars and same temperatures.

Tab. 14: Mean nymphal developmental period of *Geocoris ochropterus* with L_1 and L_2 *Thrips tabaci* as prey on cucumber leaves at different temperatures

Temp. (±1°C)	Prey stage	n	Developmental period (days)					Total (N_1 to adult) (days) Mean±SE
			N_1 Mean±SE	N_2 Mean±SE	N_3 Mean±SE	N_4 Mean±SE	N_5 Mean±SE	
18	L_1	20	17.0±1.1aB	12.8±1.1aB	21.8±1.3aB	20.6±1.5aB	27.6±1.6aB	99.8±2.4aB
	L_2	20	17.8±1.3aB	13.0±1.0aB	22.0±1.2aB	21.8±1.3aB	27.5±2.1aB	102.0±4.6aB
30	L_1	20	5.7±0.2aA	5.1±0.3aA	4.6±0.2aA	4.7±0.2aA	7.7±0.3aA	27.7±0.8aA
	L_2	20	5.9±0.2aA	5.3±0.2aA	4.9±0.1aA	4.5±0.1aA	7.4±0.2aA	28.1±0.6aA

Means in columns with different small letters indicate significant differences between different prey stages within same predator instars and temperatures, the means in columns with different capital letters indicate significant differences between different temperatures within same predator instars at p≤5% (two-factor ANOVA)

Mortality

The mortality occurred within nymphal stages of *G. ochropterus* with both L_1 and L_2 *T. tabaci* as prey on cucumber leaves at the two temperatures is demonstrated in Fig. 31. At temperature 18°C, total mortality from N_1 instar to adult emergence of the predator was 75% and 80% with L_1 and L_2 thrips as prey, respectively. At temperature 30°C, the total mortality significantly declined to 25% and 20% with L_1 and L_2 thrips as prey, respectively. At 18°C, the mortality of *G. ochropterus* most occurred within first two instars with 25-30%. At 30°C, the mortality during first and last instars was 5-10%.

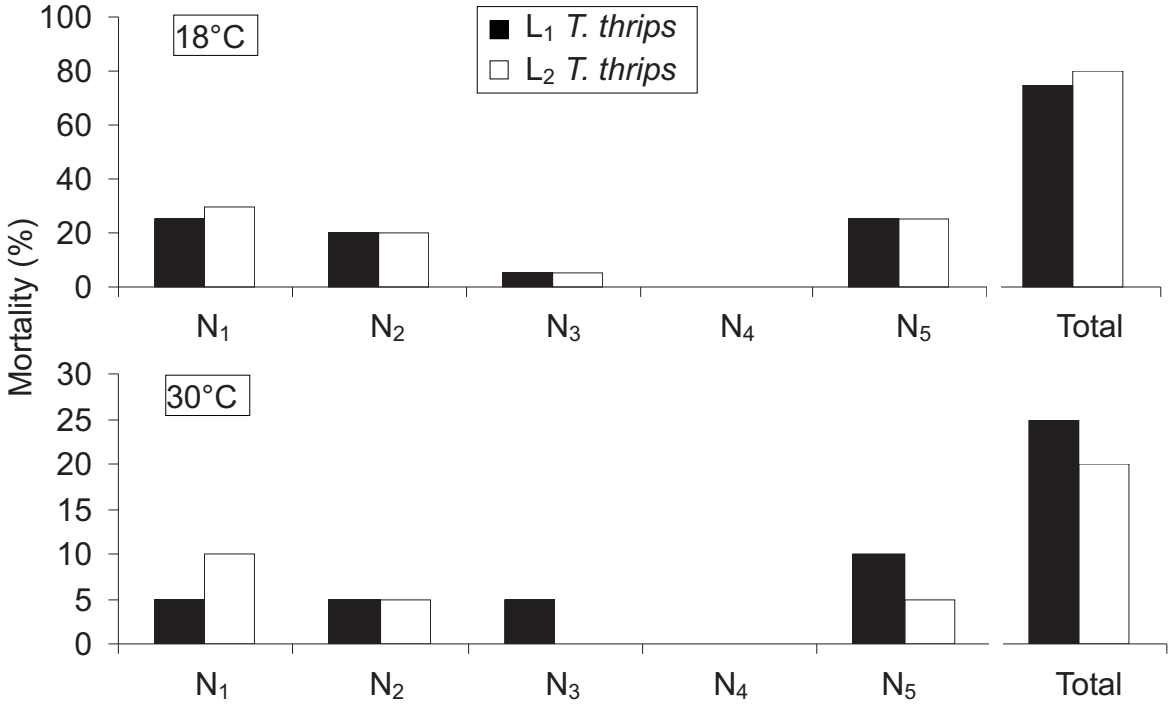

Fig. 31: Percentage mortality of *Geocoris ochropterus* during nymphal development with L_1 and L_2 *Thrips tabaci* as prey on cucumber leaves at temperature 18 and 30±1°C

Sex ratio

G. ochropterus eggs, which were laid by the adult females during the 3rd, 6th and 9th weeks after emergence at temperature 25°C, were collected. In order to obtain the sex ratio, they were reared to adults with mixed population of *T. tabaci* as prey at different temperatures. The percentage of females and males at the two temperatures were counted and showed in Fig. 32. At 18°C, the

percentage of females was 51.7% among the individuals developed from the 3rd week-laid eggs. The percentage was 58.1% for the 6th week-laid eggs and 46.9% for the 9th week. At 30°C, the percentage of females was 60.8% for the 3rd week-laid eggs, 58.2% for 6th week-laid eggs and 53.2% for the 9th week-laid eggs.

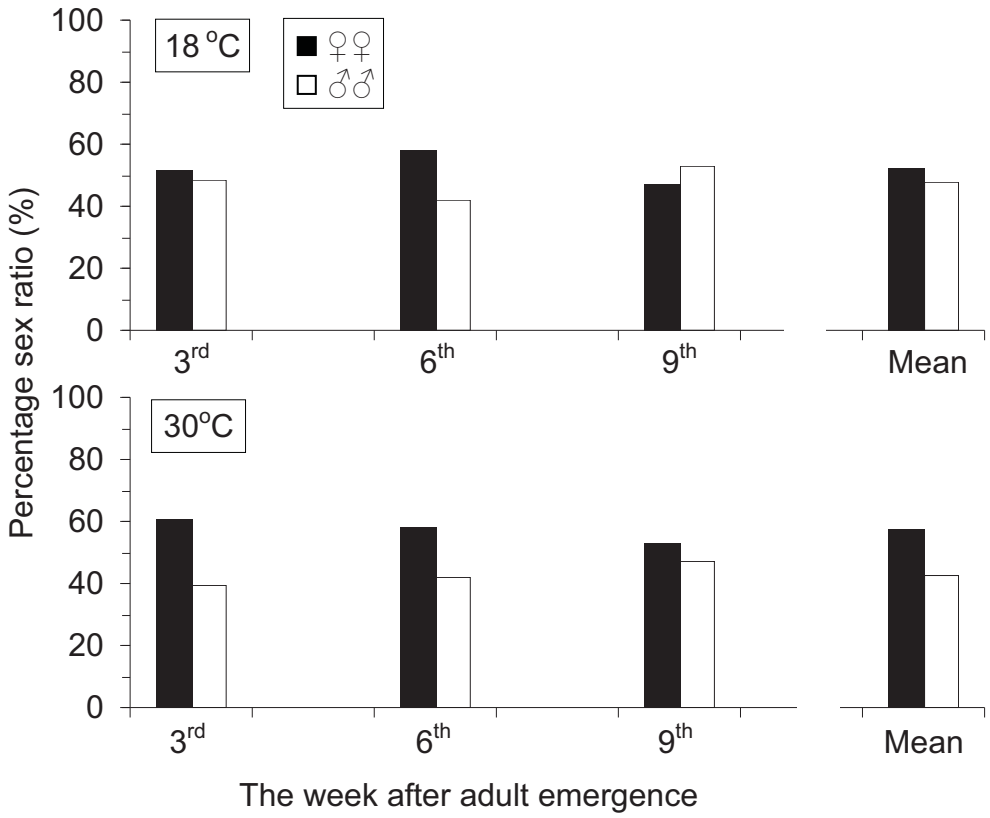

Fig. 32: Weekly summarized percentage sex ratio of *Geocoris ochropterus* by feeding on mixed population of *Thrips tabaci* as prey on cucumber leaves at temperatures 18 and 30±1°C

Longevity

By feeding on L_1 and L_2 *T. tabaci* as prey, adult *G. ochropterus* lived significantly longer at temperature 18°C than at 30°C (Fig. 33). Its longevity was a mean of 75.3 ♀♀, 76.2 ♂♂ days with L_1 thrips as prey, or 81.8 ♀♀, 75.8 ♂♂ days with L_2 thrips. At temperature 30°C, *G. ochropterus* lived for a mean longevity of 32.6 ♀♀, 33.8 ♂♂ days with L_1 thrips, or 39.0 ♀♀, 35.3 ♂♂ days with L_2 thrips. At same temperatures, the longevity of adult females was not significantly different from that of adult males. The prey stages also had no significant influence on the longevity at each temperature.

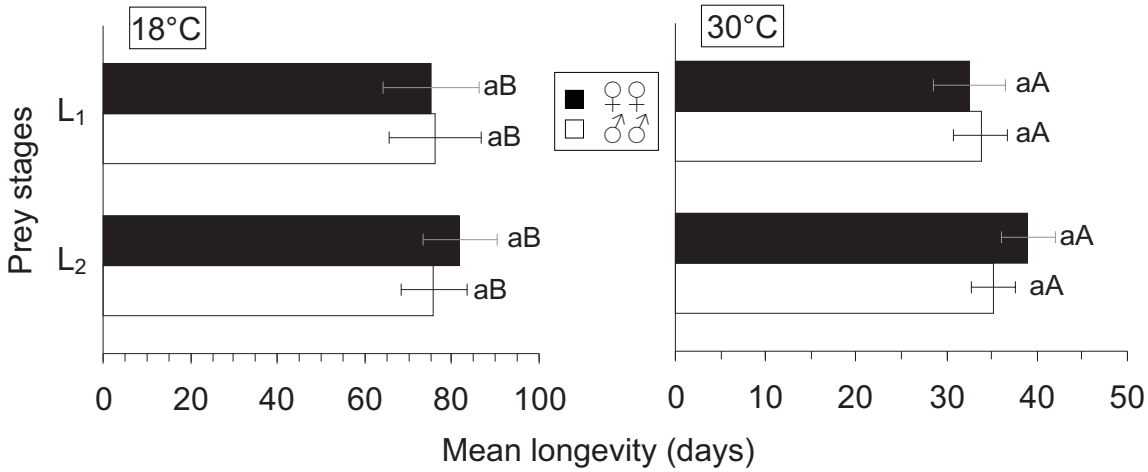

Fig. 33: Mean longevity of adult females and males of *Geocoris ochropterus* with L_1 and L_2 *Thrips tabaci* as prey on cucumber leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the female and male within the same temperature, while bars with different capital letters indicate significant differences between different temperatures within the same prey stages and sex at p≤5% (two-factor ANOVA)]

Fecundity

With mixed population of *T. tabaci* as prey, the oviposition periods, daily and total fecundity of *G. ochropterus* had been investigated at the two temperatures.

Oviposition period

Table 15 lists the mean periods of pre-oviposition, oviposition and post-oviposition of *G. ochropterus*.

Tab.15: Mean periods of pre-oviposition, oviposition and post-oviposition of *Geocoris ochropterus* by feeding on mixed population of *Thrips tabaci* as prey on cucumber leaves at different temperatures

Temperature (±1°C)	n	Period of (days)					
		Pre-oviposition		Oviposition		Post-oviposition	
		Mean±SE	Min.-Max.	Mean±SE	Min.-Max.	Mean±SE	Min.-Max.
18	10	28.6±0.8 a	25 - 32	57.0±6.3 a	12 - 71	5.2±1.4 a	0 - 14
30	10	4.4±0.2 b	4 - 5	29.4±1.6 b	19 - 34	3.6±0.7 a	0 - 6

Means in columns with different letters indicate significant difference between the predator species at P≤5% (one-factor ANOVA).

Adult females of *G. ochropterus* took significantly more days to started oviposition at temperature 18°C than at 30°C. The pre-oviposition period was a mean of 28.6 days at 18°C. While at 30°C, it was a mean of 4.4 days. The oviposition period also lasted significantly longer at 18°C than at 30°C with a mean of 57.0 and 29.4 days, respectively. The post-oviposition period was not significantly different between the two temperatures, and range from 0-14 days.

Daily and total fecundity

With mixed population of *T. tabaci* as prey at temperature 18°C, *G. ochropterus* began to lay eggs in a mean of 0.2 eggs/♀ on 26th day after emergence (Fig. 34). From then on, its daily fecundity was in dynamics with a maximum of 1.9 eggs/♀ on 33rd day. After 99th day, the oviposition stopped. The total number of eggs laid during the whole longevity was a mean of 37.3 eggs/♀.

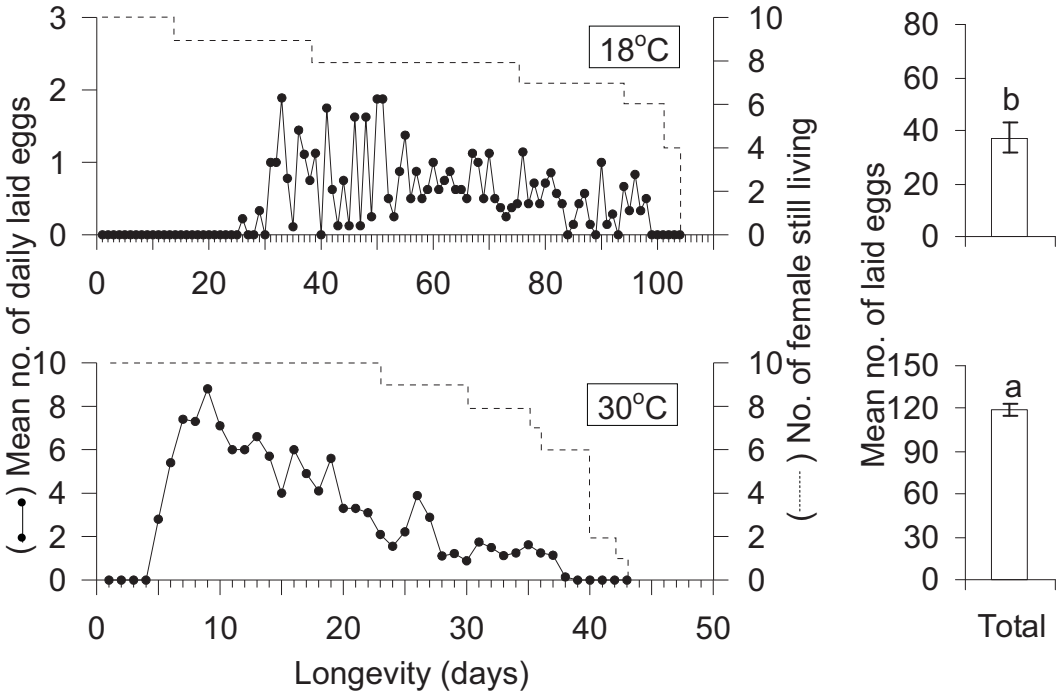

Fig. 34: Mean number of daily laid and total eggs by *Geocoris ochropterus* females during the oviposition period with mixed population of *Thrips tabaci* as prey on cucumber leaves at temperature 18 and 30±1°C [Bars with different letters indicate significant difference between the two temperatures at p≤5% (one-factor ANOVA)]

At 30°C temperature, oviposition of *G. ochropterus* was first recorded on 5th day after adult emergence, where it produced a mean of 2.8 eggs/♀. From then on, the predatory females kept

laying eggs until 38th day. The daily fecundity fluctuated with a maximum of 8.8 eggs/♀ on 9h day. The eggs laid by the females over the whole longevity were totaled a mean of 119.6 eggs/♀. It was significantly higher than the total fecundity at 18°C.

3.1.2.3 With *Gynaikothrips ficorum* as prey

Development

By feeding on L_1 and L_2 *G. ficorum* as prey, the embryonic and nymphal developments of *G. ochropterus* were observed at 18 and 30±1°C temperatures.

Embryonic development

G. ochropterus eggs hatched in a mean of 41.7 days at 18°C. They developed significantly faster at 30°C, where the embryonic period was a mean of 11.1 days (Tab. 16).

Tab. 16: Mean embryonic developmental period of *Geocoris ochropterus* on *Ficus microcarpa* leaves at two different temperatures

Temperature (±1°C)	n	Embryonic developmental period (days)	
		Mean±SE	Min. - Max.
18	20	41.7±0.3	40 - 44
30	20	11.1±0.2	10 - 12

Means in columns with different small letters indicate significant differences at $p \leq 0.01$ (one-factor ANOVA)

Nymphal development

By feeding on L_1 and L_2 *G. ficorum* as prey at 18°C (Tab. 17), it took 12.9-26.7 days for *G. ochropterus* to complete an instar. The total development from N_1 to adult emergence took a mean period of 96.3 days with L_1 thrips as prey, or 93.7 days with L_2 thrips. When the temperature increased to 30°C, *G. ochropterus* nymphs of each instar developed significantly faster. At this high temperature, the developmental period for deferent instars ranged from 4.4 to 7.2 days. The total development from N_1 to adult emergence was completed in a mean of 27.7 days with L_1 thrips as prey, or 25.9 days with L_2 thrips. No significant differences of nymphal developmental periods were tested between the both prey stages within same predator instars and same temperatures.

Tab. 17: Mean nymphal developmental period of *Geocoris ochropterus* with L_1 and L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at two temperatures

Temp. (±1°C)	Prey stages	n	Developmental period (days)					Total (N_1 to adult) (days) Mean±SE
			N_1 Mean±SE	N_2 Mean±SE	N_3 Mean±SE	N_4 Mean±SE	N_5 Mean±SE	
18	L_1	20	16.8±0.5aB	13.2±0.4aB	19.1±0.5aB	20.3±0.3aB	26.7±0.4aB	96.3±1.1aB
	L_2	20	16.6±0.3aB	12.9±0.2aB	18.1±0.3aB	19.9±0.2aB	26.2±0.3aB	93.7±0.3aB
30	L_1	20	5.9±0.2aA	4.8±0.2aA	4.8±0.3aA	4.7±0.3aA	7.2±0.2aA	27.7±0.5aA
	L_2	20	5.5±0.2aA	4.8± 0.2aA	4.4±0.3aA	4.3±0.2aA	6.8±0.2aA	25.9±0.4aA

Means in columns with different small letters indicate significant differences between different predator instars within same predator sex and prey stage, with different capital letters between different prey stages within same predator instars and sex at p≤5% (two-factor ANOVA).

Mortality

Fig. 35 shows the mortality of *G. ochropterus* during the nymphal development.

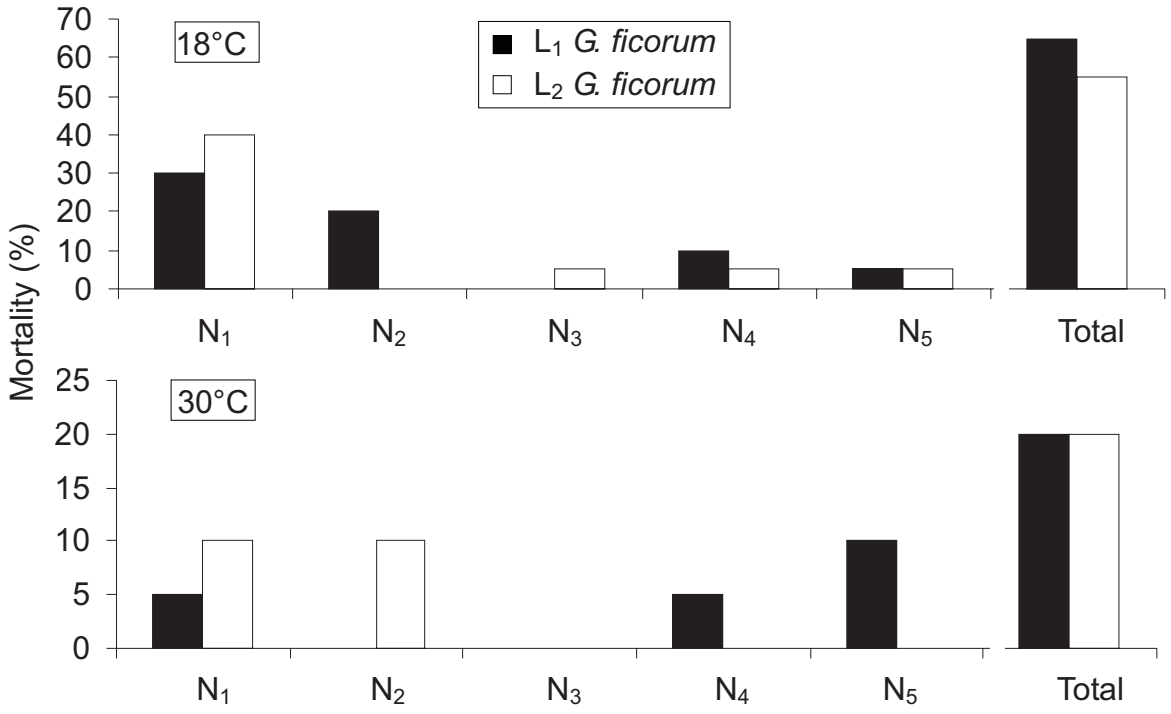

Fig. 35: Percentage mortality of *Geocoris ochropterus* during nymphal development with L_1 and L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 18 and 30±1°C

At temperature 18°C, *G. ochropterus* completed the whole nymphal development with a total mortality of 65% when L_1 larvae of *G. ficorum* were offered as prey. The total mortality was 55% with L_2 larvae of *G. ficorum* as prey. The mortality reduced when the nymphal development was conducted at 30°C, where it valued 20% in both prey age groups.

Sex ratio

The eggs of *G. ochropterus*, which were laid during 3rd, 6th and 9th weeks after adult emergence at 25°C temperature, were collected and reared at different temperatures. By feeding on mixed population of *G. ficorum* as prey, the eggs could grow into adults with different sex ratios at 18 and 30°C temperatures (Fig. 36). At 18°C, the percentage of females was 43.8, 45.2 and 40.0% for the three groups of eggs laid during the 3rd, 6th, and 9th weeks, respectively. At 30°C, the percentage of females was 59.3% for the 3rd weed-laid eggs, 50.7% for the 6th week-laid eggs and 55.9% for the 9th week-laid eggs.

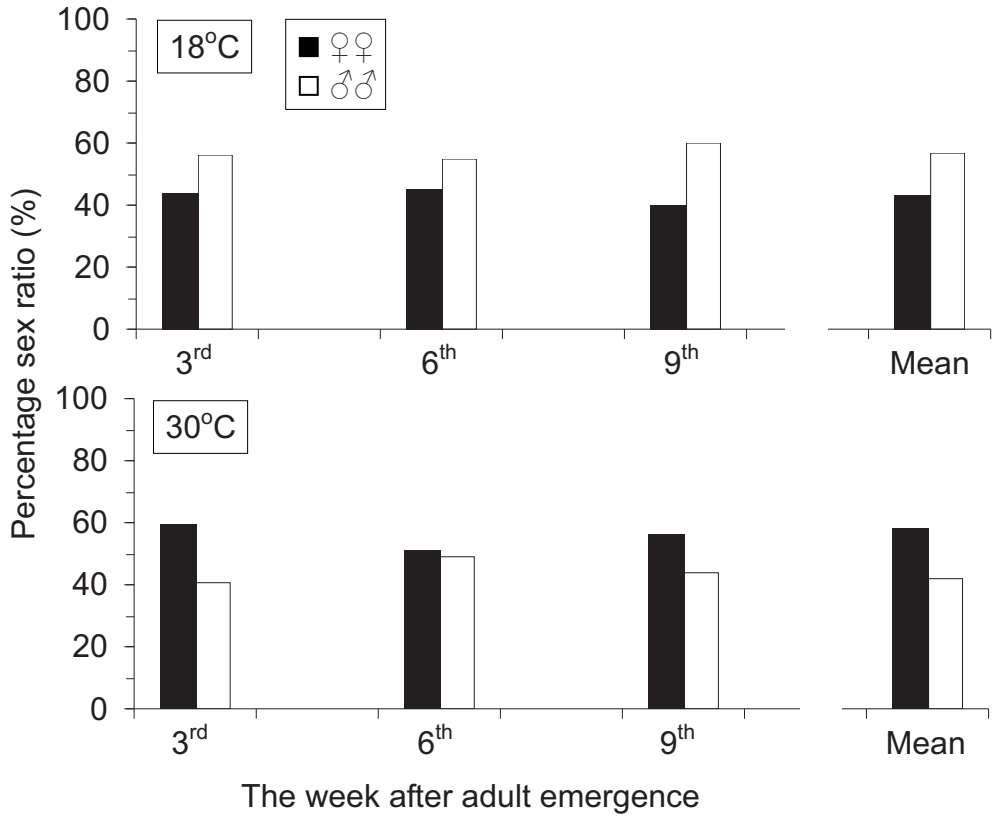

Fig. 36: Weekly summarized percentage sex ratio of *Geocoris ochropterus* by feeding on mixed population of *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperatures 18 and 30±1°C

Longevity

G. ochropterus adults lived a mean longevity of 70.7 ♀♀, 70.5 ♂♂ days with L_1 *G. ficorum* as prey, or 78.9 ♀♀, 76.4 ♂♂ days with L_2 thrips as prey at 18°C temperature (Fig. 37). At 30°C, the longevity was a mean of 31.8 ♀♀, 30.7 ♂♂ days with L_1 thrips as prey, or 34.3 ♀♀, 29.2 ♂♂ days with L_2 thrips as prey. *G. ochropterus* adults lived significantly shorter at 30°C than at 18°C. The differences of longevity between females and males were not significant at same temperatures. The longevity with L_1 thrips as prey was not significant different from that with L_2 thrips as prey at same temperatures.

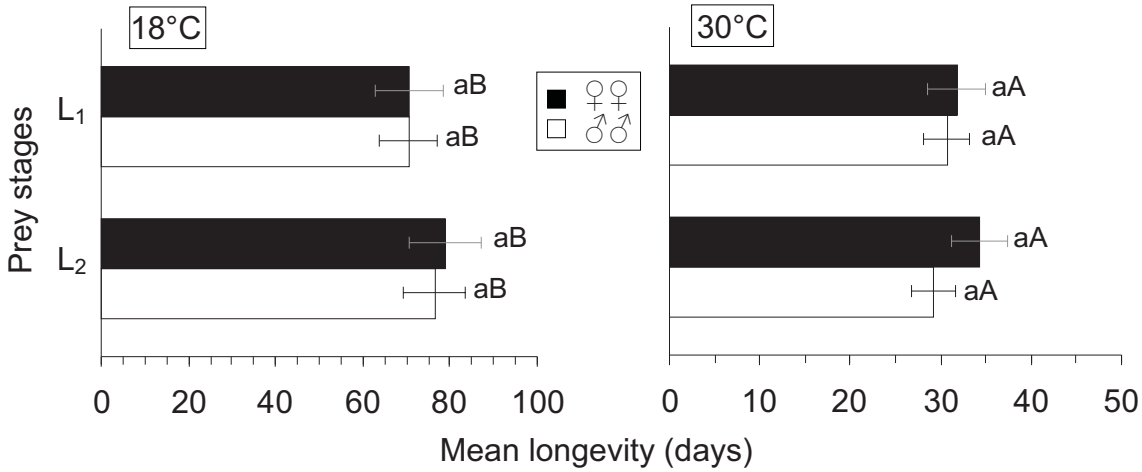

Fig. 37: Mean longevity of adult females and males of *Geocoris ochropterus* with L_1 and L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the female and male within the same temperature, while bars with different capital letters indicate significant differences between different temperatures within the same prey stages and sex at $p \leq 5\%$ (two-factor ANOVA)]

Fecundity

As important parameters of fecundity, the periods of pre-ovipostion, oviposition and post oviposition, as well as the daily ant total number of laid eggs were noted in the experiment.

Oviposition period

As listed in Tab. 18, *G. ochropterus* females started to lay eggs in 21-27 days after adult emergence with mixed population of *G. ficorum* as prey at temperature 18°C. The oviposition

was kept for 14-75 days. The females died in 0-17 days after they stopped oviposition. The mean periods of pre-oviposition, oviposition and post-oviposition for the females was 24.2, 56.3 and 10.1 days. At 30°C, the females started to lay eggs in 4-5 days after emergence with a mean of 4.2 days. The oviposition lasted for 13-35 days with a mean of 25.5 days. The females lived 0-7 days after they stopped oviposition. The periods of pre-oviposition, oviposition and post-oviposition were all significantly longer at 18°C than at 30°C.

Tab.18: Mean periods of pre-oviposition, oviposition and post-oviposition of *Geocoris ochropterus* by feeding on mixed population of *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at different temperatures

Temperature (±1°C)	n	Period of (days)					
		Pre-oviposition		Oviposition		Post-oviposition	
		Mean±SE	Min.-Max.	Mean±SE	Min.-Max.	Mean±SE	Min.-Max.
18	10	24.2±2.4 a	21 - 27	56.3±6.5 a	14 - 75	10.1±2.0 a	0 - 17
30	10	4.2±0.2 b	4 - 5	25.5±2.6 b	13 - 35	3.9±0.5 b	0 - 7

Means in columns with different letters indicate significant difference between the predator species at p≤5% (one-factor ANOVA).

Daily and total fecundity

By feeding on mixed population of *G. ficorum* as prey, *G. ochropterus* females conducted oviposition in considerably different way under the two temperatures (Fig. 38). At 18°C, *G. ochropterus* females started to lay eggs with a mean of 0.3 eggs/♀ on 22nd day after adult emergence, and its daily fecundity reached a maximum of 3.6 eggs/♀ on 38th day. The daily fecundity then decreased in fluctuation until 99th day when the females stopped oviposition. At 30°C, the oviposition was started on 5th day with a mean of 2.6 eggs/♀. The maximum of the daily fecundity was recorded as a mean of 8.6 eggs/♀ on the 14th day. After that, the daily fecundity declined in fluctuation to zero after the 40th day.

Over the whole longevity at 18 and 30°C, the mean total fecundity of *G. ochropterus* was 52.6 and 128.1 eggs/♀, respectively. *G. ochropterus* showed significantly more fecundity at 30°C than at 18°C.

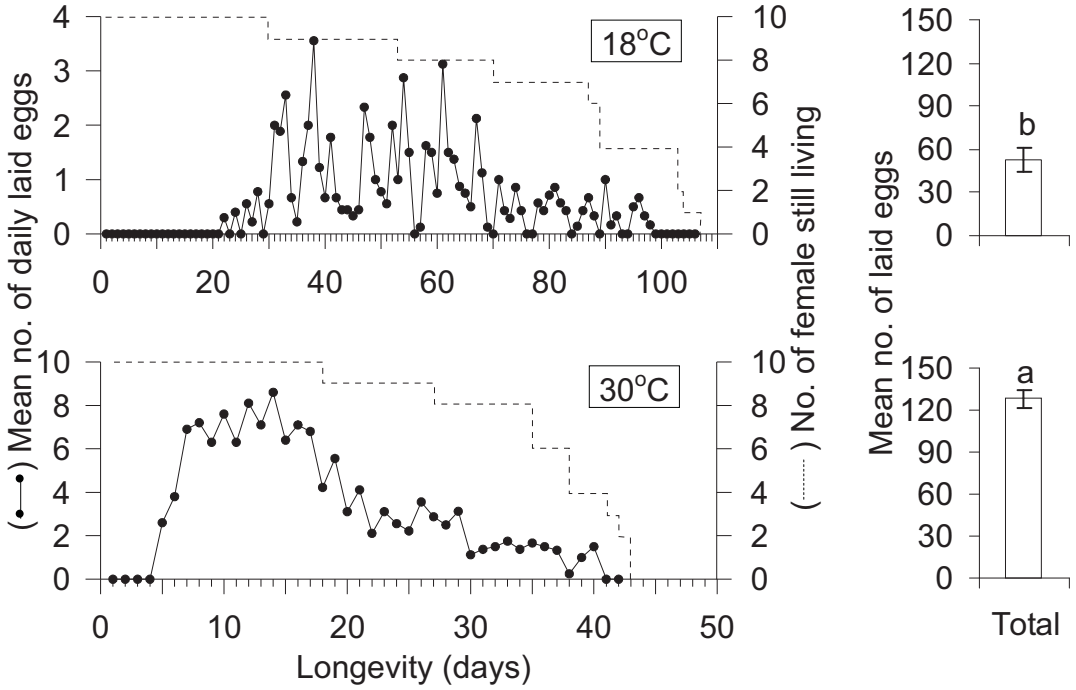

Fig. 38: Mean number of daily ant total laid eggs by *Geocoris ochropterus* females during the oviposition period by feeding on mixed population of *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 18 and 30±1°C. [Bars with different letters indicate significant difference between the two temperatures at p≤5% (one-factor ANOVA)]

3.1.3 Prey consumption by *Geocoris ochropterus* at temperature 18 and 30°C

3.1.3.1 With *Frankliniella occidentalis* as prey

The prey consumption by the nymphal and adult predators was determined with L_1 and L_2 *F. occidentalis* as prey.

Prey consumption by the nymphal predator

Fig. 39 presents the prey consumption by *G. ochropterus* nymphs at the two temperatures. At temperature 18°C, the predatory nymphs consumed a mean of 0.3 L_1 or L_2 *F. occidentalis* on the 1st day after hatching. The daily prey consumption then increased gradually to reach a peak of 5.8 L_1 or 3.0 L_2 thrips by the N_5 instars on the 86th and 101st days after hatching, respectively. At 30°C, the daily prey consumption by the predatory nymphs was 1.5 L_1 or 0.9 L_2 thrips on the 1st day after hatching, and then increased gradually to reach a peak of 99.8 L_1 or 17.6 L_2 thrips on the 32nd and 30th days after hatching, respectively.

Throughout the whole nymphal development, the daily prey consumption by the predatory nymphs was averaged 2.3 L_1 or 0.7 L_2 thrips at 18°C. While at 30°C, it was averaged 25.0 L_1 or 6.6 L_2 thrips at 30°C. The nymphs consumed the thrips of same stages with significantly higher efficiency at 30°C than at 18°C. At same temperatures, the nymphs daily consumed significantly more L_1 than L_2 thrips.

Total prey consumption during the nymphal development was a mean of 226.0 L_1 or 124.3 L_2 thrips at 18°C. It was a mean of 753.0 L_1 or 195.9 L_2 thrips at 30°C. The mean total prey consumption by the predatory nymphs with same prey ages was significantly higher at 30°C than at 18°C. The mean total number of L_1 thrips consumed by the nymphs was also significantly higher than that of L_2 thrips at the same temperatures.

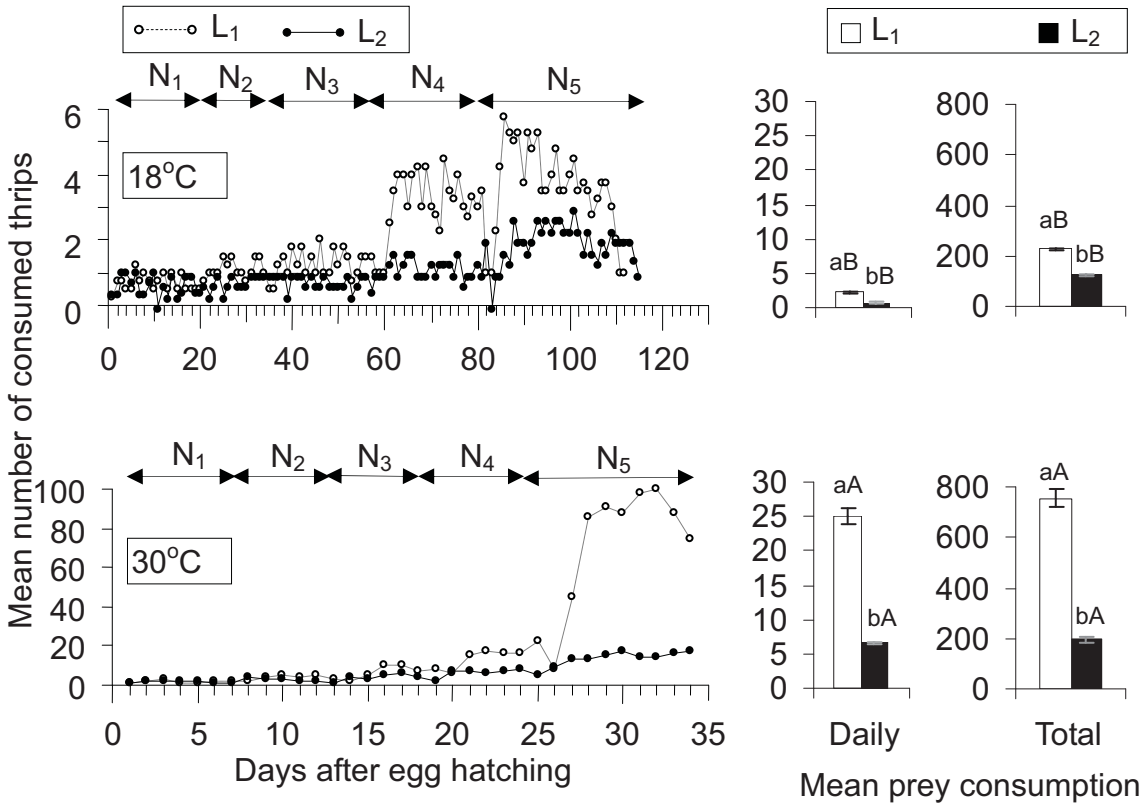

Fig. 39: Mean daily and total prey consumption by nymphs of *Geocoris ochropterus* during development with L_1 and L_2 *Frankliniella occidentalis* as prey on cucumber leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the prey stages within the same temperature. Bars with different capital letters indicate significant differences between different temperatures within the same prey stage at $p \leq 5\%$ (two-factor ANOVA)]

Prey consumption by the adult predator

With L_1 and L_2 *F. occidentalis* as prey, the females of *G. ochropteurs* began to consume a mean of 4.5 L_1 or 2.0 L_2 thrips on the 1st day after adult emergence at temperature 18°C (Fig. 40). Afterwards, the mean daily consumption increased irregularly until reached a peak of 14.3 L_1 or 8.0 L_2 thrips/♀ on the 22nd and 51st days, respectively. At 18°C, the males started to feed on a mean of 3.3 L_1 or 2.3 L_2 thrips on the 1st day after adult emergence. Hereafter, the mean daily prey consumption by the adult males fluctuated over the longevity with a maximum of 11.7 L_1 or 8.0 L_2 thrips on 21st and 12th days after adult emergence, respectively.

At 30°C, the females killed 49.0 L_1 or 31.7 L_2 thrips on the 1st day, and then the mean daily prey consumption fluctuated over the longevity with a maximum of 89.3 L_1 or 53.0 L_2 thrips on the 17th and 7th days, respectively. For the adult males of *G. ochropterus*, the mean daily prey consumption was 28.3 L_1 or 20.3 L_2 thrips on the 1st day after adult emergence. It then varied with a maximum of 78.4 L_1 or 42.8 L_2 thrips on the 22nd and 13th days, respectively.

The daily prey consumption by the adult females throughout whole longevity was averaged 6.3 L_1 or 3.4 L_2 thrips at 18°C, and it was 63.7 L_1 and 37.7 L_2 thrips at 30°C. In adult males, the daily prey consumption over longevity was averaged 5.7 L_1 or 2.6 L_2 thrips at 18°C, and 54.2 L_1 or 31.8 L_2 thrips at 30°C. Statistically, adult *G. ochropterus* daily consumed significantly more thrips at 30°C than at 18°C. At same temperatures, the adults of both sexes killed significantly more L_1 than L_2 thrips. The females daily consumed significantly more thrips than the males with both prey stages as prey at 30°C.

The mean total prey consumption by the females was 382.0 L_1 or 226.7 L_2 thrips at 18°C, and 1974.0 L_1 or 1132.8 L_2 thrips at 30°C. The males consumed a mean total prey consumption of 357.2 L_1 or 168.8 L_2 thrips at 18°C, and 1611.8 L_1 or 900.3 L_2 thrips at 30°C. The total prey consumption within same prey stages was significantly higher at 30°C than at 18°C. It was significantly higher at same temperatures with L_1 thrips as prey than with L_2 thrips as prey. At 30°C, the total prey consumption by the females was significantly higher than that by the males within same prey stages.

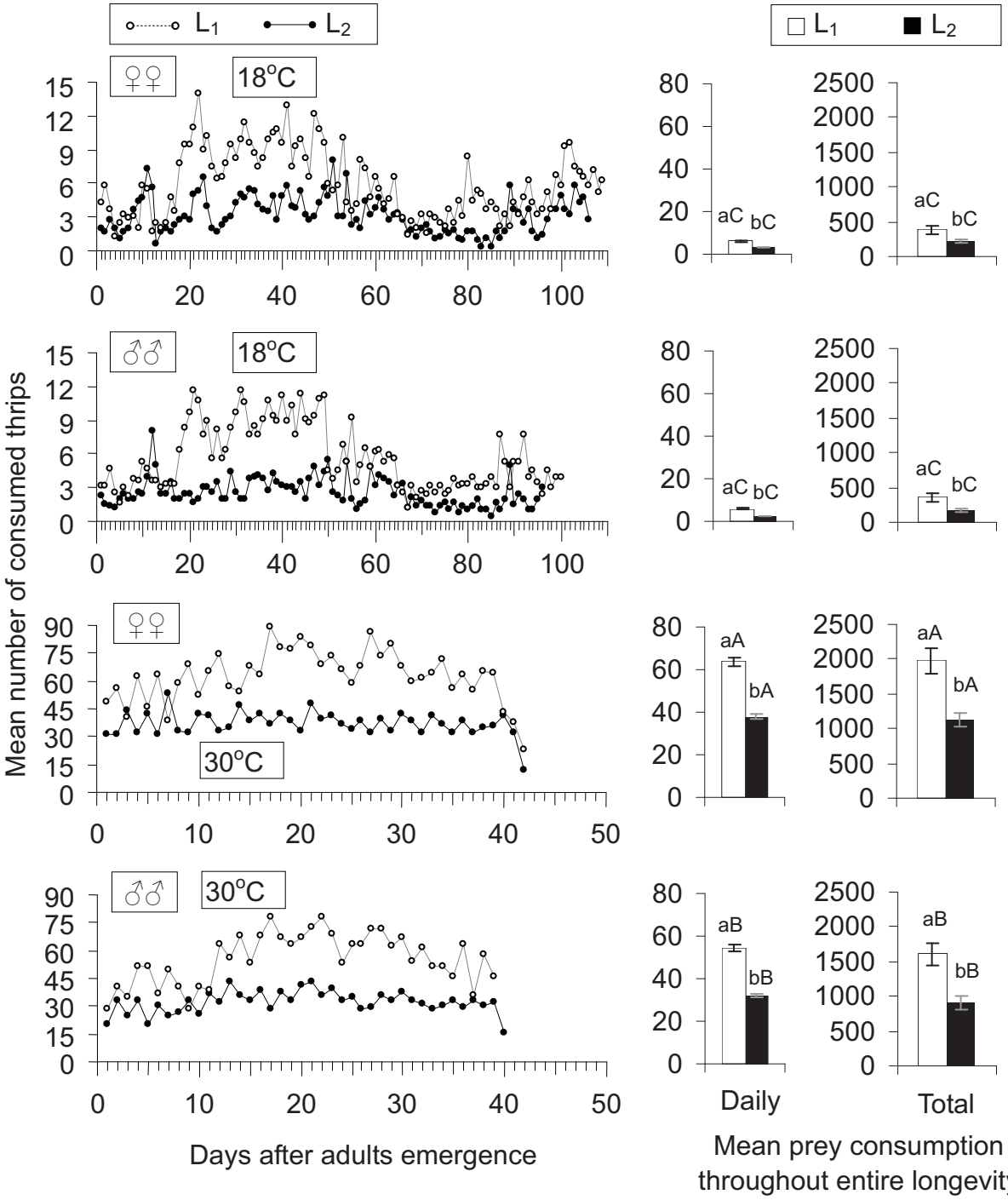

Fig. 40: Mean daily and total prey consumption by females and males of *Geocoris ochropterus* with L_1 and L_2 *Frankliniella occidentalis* as prey on cucumber leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the prey stages within the same predator sex and temperature. Bars with different capital letters indicate significant differences between different temperatures within the same prey stage at $p \leq 5\%$ (two-factor ANOVA)]

3.1.3.2 With *Thrips tabaci* as prey

The experiments here have conducted to determine the prey consumption by the nymphal and adult predators with L_1 and L_2 *T. tabaci* as prey at two different temperatures.

Prey consumption by the nymphal predator

As shown in Fig. 41, the nymphs started predation with a mean of 0.6 L_1 or 0.5 L_2 thrips on the 1st day after hatching at temperature 18°C. From then on, the daily prey consumption increased irregularly with a maximum of 5.6 L_1 thrips by the N_4 istar on the 78th day, or 5.0 L_2 thrips by the N_5 instars on the 108th days. At temperature 30°C, the nymphs consumed a mean of 1.2 L_1 or 1.1 L_2 thrips on the 1st day. From then on, the daily prey consumption increased gradually with a maximum of 98.4 L_1 or 20.6 L_2 thrips on the 30th and 31st days, respectively.

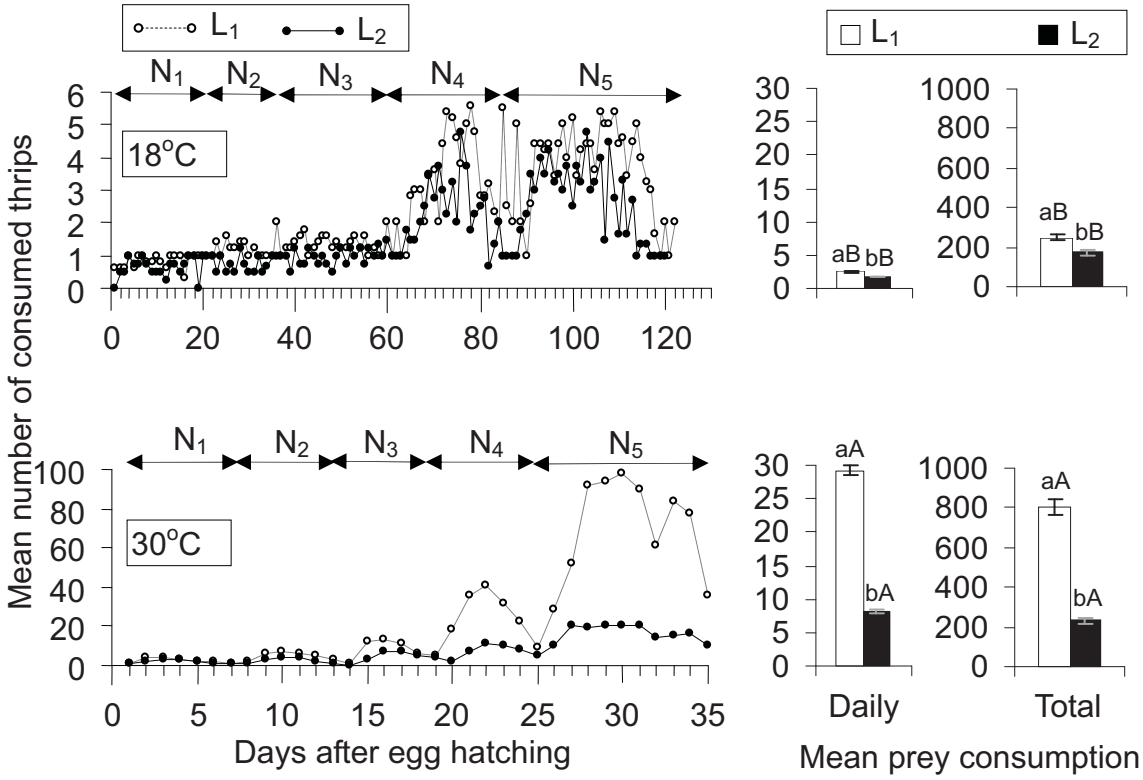

Fig. 41: Mean daily and total prey consumption by nymphs of *Geocoris ochropterus* during development with L_1 and L_2 *Thrips tabaci* as prey on cucumber leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the prey stages within the same temperature. Bars with different capital letters indicate significant differences between different temperatures within the same prey stage at p≤5% (two-factor ANOVA)]

When data were pooled over the whole nymphal development, the daily prey consumption by the nymphs was averaged 2.5 L_1 or 1.7 L_2 thrips at 18°C, and 29.3 L_1 or 8.2 L_2 thrips at 30°C. The daily prey consumption over the whole nymphal period was significantly higher with L_1 thrips as prey than with L_2 thrips within same temperatures. It was also significantly higher at 30°C than at 18°C within same prey stages.

The number of larvae consumed by the nymphs over the whole nymphal development was totaled a mean of 245.8 L_1 or 174.3 L_2 thrips at 18°C, and 804.8 L_1 or 232.2 L_2 thrips at 30°C. In terms of total prey consumption, the nymphs consumed significantly more L_1 than L_2 thrips within same temperature. They also showed significantly higher total prey consumption at 30°C than at 18°C within same prey stages.

Prey consumption by the adult predator

By feeding on L_1 and L_2 instars of *T. tabaci* as prey, predation efficiency of the adult females and males of *G. ochropterus* increased considerably with higher temperature (Fig. 42). At temperature 18°C, the daily prey consumption by the females was a mean of 6.0 L_1 or 1.5 L_2 thrips on the 1st day after adult emergence. From then on, it fluctuated over the longevity with a maximum of 13.3 L_1 or 6.7 L_2 thrips on the 24th or 11th day, respectively. For the males, the daily prey consumption was a mean of 3.0 L_1 or 1.3 L_2 thrips on the 1st day. It reached a maximum of 11.7 L_1 or 6.2 L_2 thrips on 31st or 62nd days, respectively.

At 30°C, daily prey consumption by the females was a mean of 36.5 L_1 or 14.1 L_2 thrips on the 1st day after adult emergence. It displayed a maximum of 79.2 L_1 or 45.1 L_2 thrips on the 5th or 13th days, respectively. On the 1st day after adult emergence, the males consumed a mean of 30.5 L_1 or 15.9 L_2 thrips. The males were recorded a highest daily prey consumption of 69.8 L_1 or 41.5 L_2 thrips on the 23rd or 9th days, respectively.

The prey consumptions on every day during the whole longevity were averaged 8.8 L_1, 4.5 L_2 thrips/♀, and 6.6 L_1, 3.9 L_2 thrips/♂ at 18°C. They were averaged 61.5 L_1, 36.8 L_2 thrips/♀, and 58.5 L_1, 33.5 L_2 thrips/♂ at 30°C. Both females and males showed significantly higher predation efficiency on L_1 than on L_2 thrips as prey within same temperatures. The predation efficiency increased significantly as the temperature increased from 18 to 30°C.

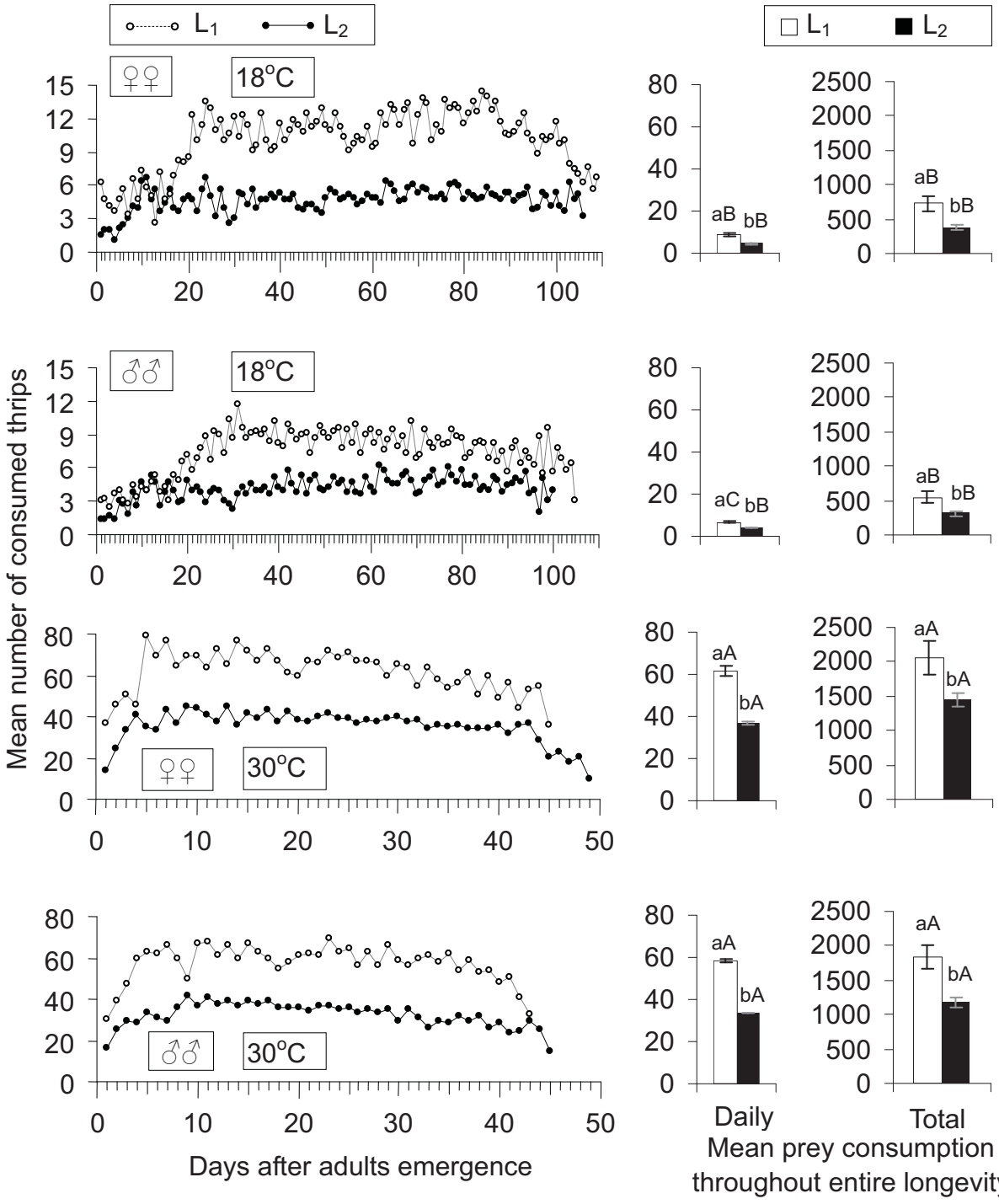

Fig. 42: Mean daily and total prey consumption by females and males of *Geocoris ochropterus* with L_1 and L_2 *Thrips tabaci* as prey on cucumber leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the prey stages within the same predator sex and temperature. Bars with different capital letters indicate significant differences between different temperatures within the same prey stage at $p \leq 5\%$ (two-factor ANOVA)]

The total number of thrips larvae consumed by *G. ochropterus* during the longevity was averaged 727.7 L_1, 374.7 L_2 thrips/♀, and 550.2 L_1, 310.8 L_2 thrips/♂ at 18°C. It was averaged 2059.8 L_1, 1444.3 L_2 thrips/♀, and 1848.2 L_1, 1178.7 L_2 thrips/♂ at 30°C. Within same temperatures, the females and males had significantly higher total prey consumption on L_1 than on L_2 thrips as prey. Within same prey stages, the mean total prey consumption was significantly higher at 30°C than at 18°C. The total prey consumption was not significantly different between the females and males within same prey stage and temperature.

3.1.3.3 With *Gynaikothrips ficorum* as prey

Prey consumptions by the nymphal and adult *G. ochropterus* were investigated in the experiment.

Prey consumption by the nymphal predator

Figure 43 shows the prey consumption by the nymphs of *G. ochropterus* during the development.

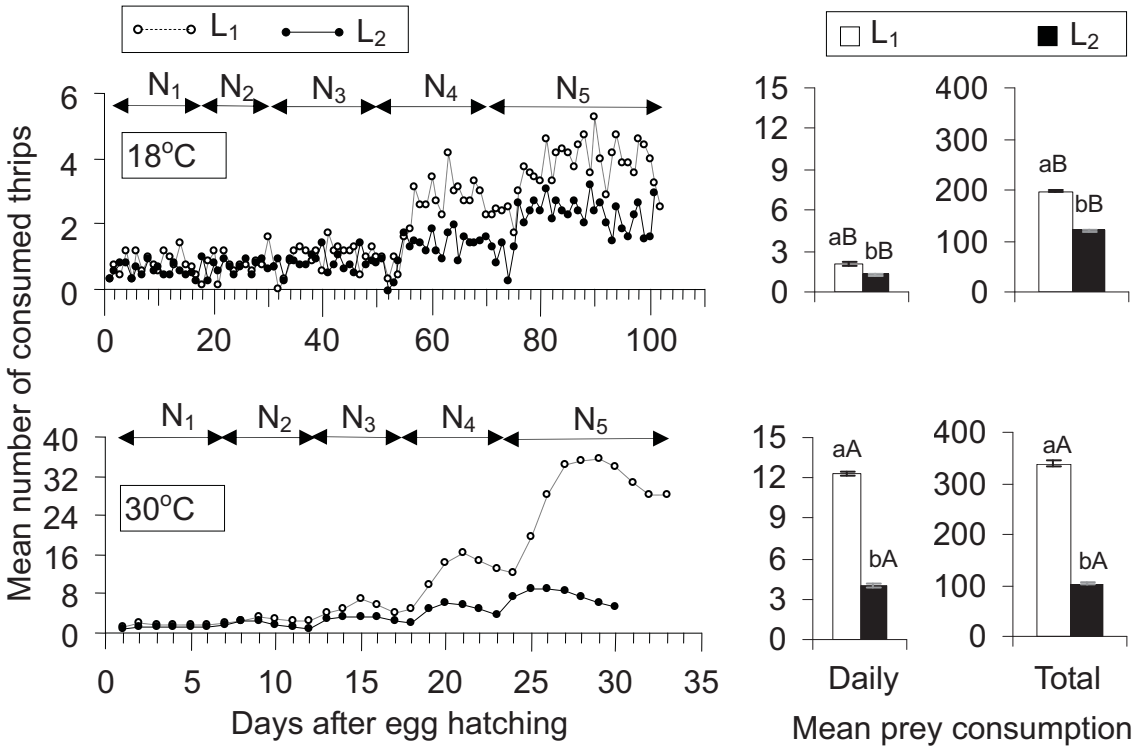

Fig. 43: Mean daily and total prey consumption by nymphs of *Geocoris ochropterus* during development by feeding on L_1 and L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves of at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the prey stages within the same temperature. Bars with different capital letters indicate significant differences between different temperatures within the same prey stage at $p \leq 5\%$ (two-factor ANOVA)]

By feeding on L_1 and L_2 *G. ficorum* as prey, the daily prey consumption of *G. ochropterus* nymphs increased with the instars. At temperature 18°C, the daily prey consumption was 0.3-1.4 L_1 thrips and 0.3-0.9 L_2 thrips during the N_1 instar. The nymphs daily consumed more prey number as it developed. During the N_5 instar, the nymphs daily consumed 1.7-5.3 L_1 thrips, and 1.3-3.2 L_2 thrips. At 30°C, the nymphs daily consumed 1.4-2.1 L_1 thrips, and 1.0-1.8 L_2 thrips during the N_1 istar. They daily consumed 28.0-35.4 L_1 thrips, and 5.3-9.1 L_2 thrips during the N_5 instar.

During whole nymphal development, the daily prey consumption by the predatory nymphs was averaged a mean of 2.1 L_1 or 1.3 L_2 thrips at 18°C, and it was a mean of 12.3 L_1 or 4.0 L_2 thrips at 30°C. The total prey consumption during the nymphal development was 196.7 L_1 or 120.6 L_2 thrips at 18°C, and it was 339.1 L_1 or 103.6 L_2 thrips at 30°C. The predatory nymphs consumed significantly more L_1 than L_2 thrips as prey within same temperature. They also exhibited significantly higher mean daily and total prey consumption at 30°C than at 18°C within the same prey stage.

Prey consumption by the adult predator

With *G. ficorum* larvae as prey at temperature 18°C, *G. ochropteurs* females daily consumed 1.2-4.8 L_1 and 1.2-4.2 L_2 thrips during the whole longevity (Fig. 44). The daily prey consumption for the males was 1.4-8.2 L_1 and 1.2-4.2 L_2 thrips. By feeding on the thrips larvae at 30°C, the females daily mean consumed 10.5-28.5 L_1 and 5.3-16.4 L_2 thrips over the longevity. The males, on the other hand, daily consumed 7.7-23.3 L_1 and 5.5-14.0 L_2 thrips.

Over the whole longevity, the daily prey consumption was averaged 5.9 L_1, 3.5 L_2 thrips for the females, and 5.1 L_1, 2.9 L_2 thrips for the males at 18°C. While at 30°C, the daily prey consumption was averaged 18.6 L_1, 10.1 L_2 thrips/♀, and 17.0 L_1, 11.2 L_2 thrips/♂. The total prey consumption was 427.2 L_1, 271.6 L_2 thrips/♀ and 368.8 L_1, 227.2 L_2 thrips/♂ at 18°C. It was 595.4 L_1, 388.0 L_2 thrips/♀ and 528.7 L_1, 298.3 L_2 thrips/♂ at 30°C. Within same temperatures, both females and males consumed significantly more L_1 thrips than L_2 thrips. Within same prey stages, both females and males consumed significantly more thrips larvae at 30°C than at 18°C.

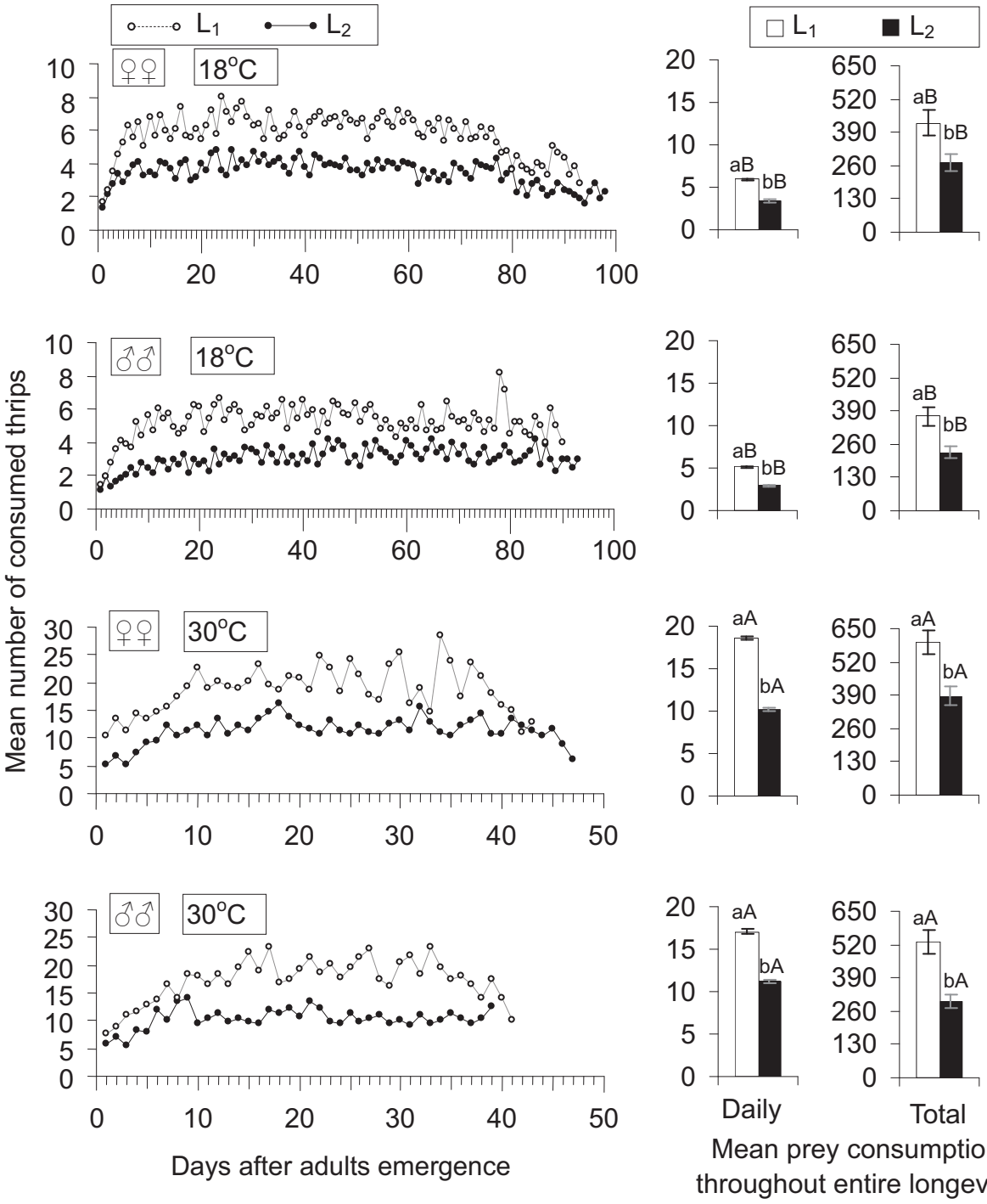

Fig. 44: Mean daily and total prey consumption by adults of *Geocoris ochropterus* with L_1 and L_2 *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 18 and 30±1°C. [Bars with different small letters indicate significant differences between the prey stages within the same predator sex and temperature. Bars with different capital letters indicate significant differences between different temperatures within the same prey stage at $p \leq 5\%$ (two-factor ANOVA)]

3.1.4 Prey consumption by *Geocoris ochropterus* in changing prey offer

Prey consumption by 7-day-old adult females of *G. ochropterus* was investigated under 4 regimes of changing prey offer. The predators were continuously observed over a period of 3 experiment weeks with L_2 of *F. occidentalis*, *T. tabaci* and *G. ficorum* exclusively offered as prey at temperature 25±1°C. During the 1st and 3rd weeks of experiment, 50 (regime 1), 20 (regime 2), 10 (regime 3), 5 (regime 4) thrips/♀ were daily offered as prey. During the 2nd week of experiment, 30 thrips/♀ were daily offered in all regimes. The results showed that the females could adapt to the changing prey density of the 3 thrips species (Fig. 45).

During the 1st week with *F. occidentalis* as prey, *G. ochropterus* females daily consumed average 19.8-21.0 thrips in regime 1. The females daily consumed average 14.2-17.2, 6.4-8.9 and 2.0-4.1 thrips in regime 2, 3 and 4, respectively. The mean daily prey consumption over the whole 1st week was significantly higher in the regimes with more thrips offered as prey. During the 2nd week, when 30 thrips/♀ were daily offered in all the regimes, the daily prey consumption decreased in regime 1, but increased in the other 3 regimes. Such increase was clearer in the regime 4 and 3, where 10 and 5 thrips/♀ were offered in the 1st week. During the 3rd experimental week, the daily prey consumption by the females in regime 1 ranged from 19.3 to 24.7 thrips. It significantly increased, in comparison with the 2nd week. However, in the other 3 regimes, the prey consumption showed remarkable decrease, especially in regime 3 and 4 where 5.8-8.3 and 2.1-4.2 thrips/♀ were daily consumed, respectively.

With *T. tabaci* as prey, the female of *G. ochropterus* daily consumed average 21.9-26.3 thrips in prey offering regime 1 during the 1st week. In regime 2, 3 and 4, the females consumed average 14.9-17.2, 5.2-8.1 and 1.8-4.1 thrips, respectively. The mean daily prey consumption over the whole 1st week was significantly higher in the regimes with higher prey density. During the 2nd week, the females in regime 1 significantly reduced the prey consumption as fewer prey individuals were offered. In the other 3 regimes, where more thrips were offered as prey, the females displayed significantly higher prey consumption. During the 3rd experimental week, the daily prey consumption in regime 1 significantly increased with a range from 20.8-26.6 thrips/♀. While it dropped in the other 3 regimes with the prey number reduced.

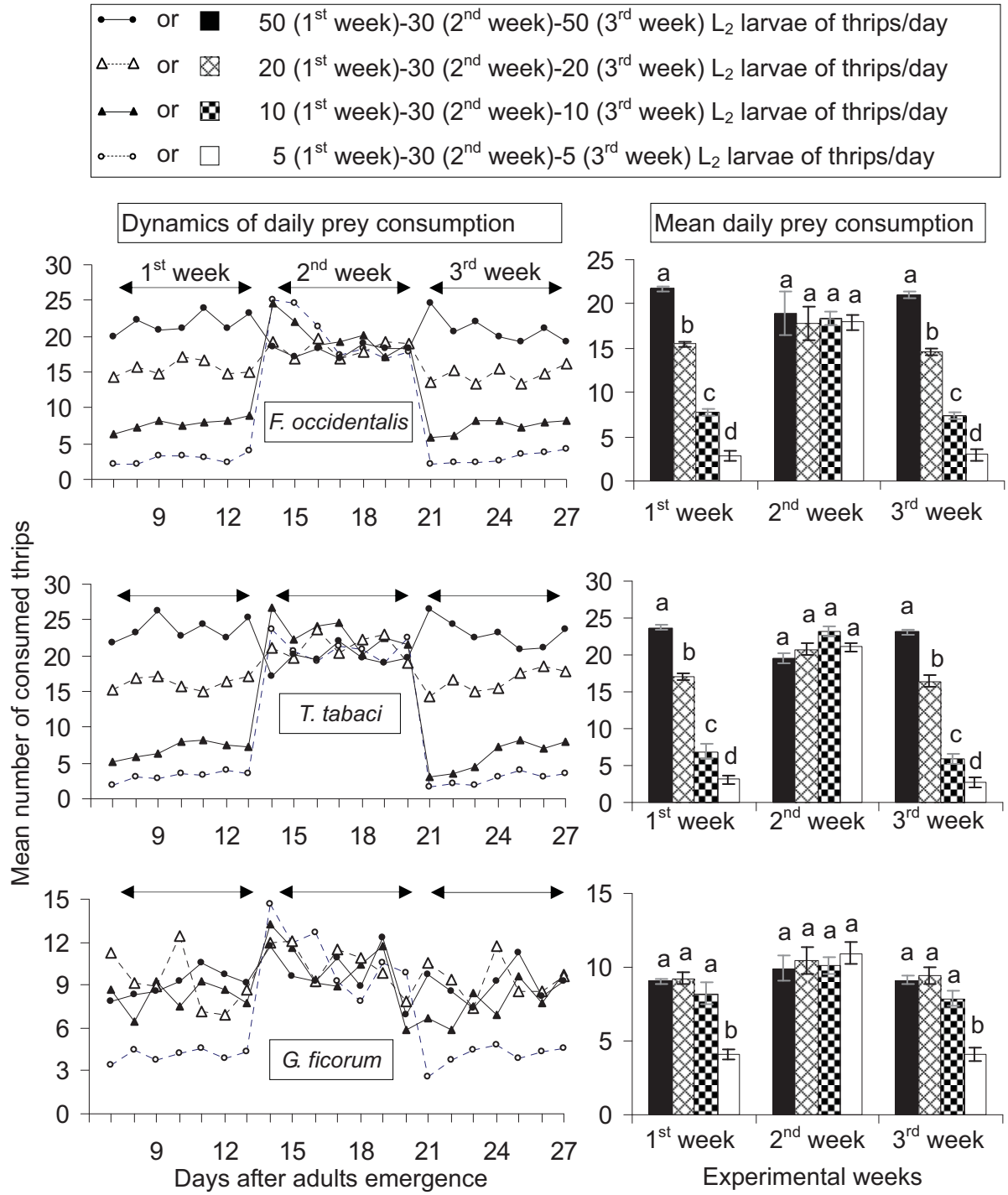

Fig. 45: Mean daily prey consumption by 7-day-old female adults of *Geocoris ochropterus* with a changing number of L_2 larvae of *Frankliniella occidentalis*, *Thrips tabaci*, *Gynaikothrips ficorum* as prey temperature 25±1°C. [Bars with different letters indicate significant difference between different prey densities within the same prey species and experimental week at p≤5% (one-factor ANOVA)]

During the 1st week with *G. ficorum* as prey, the prey consumption by the females of *G. ochropterus* was not significantly different among regime 1, 2 and 3, with a mean of 6.5-12.4 thrips. It was significantly higher than that in regime 4, where the females consumed 3.4-4.6 thrips. During the 2nd week, the females in regime 1, 2 and 3 showed no significant change of daily prey consumption, in comparison with the 1st week. However, a significant increase was recorded in regime 4. During the 2nd week, *G. ochropterus* daily consumed a mean of 5.9-14.6 thrips without significant differences among the 4 regimes. During the 3rd experimental week, the females daily consumed 5.9-11.7 thrips in regime 1, 2 and 3 without significantly difference. But in regime 4, the females showed again the significantly lower daily prey consumption (2.6-4.8 thrips) than the females in other regimes.

3.1.5 Effect of extremely high constant and changing temperatures on development and prey consumption of *Geocoris ochropterus*

The development, mortality and prey consumption of *G. ochropterus* during the immature development were observed at extremely high constant temperature 35°C and extremely high changing temperature 35/25°C (L:D) with L_2 of *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey.

Development

The embryonic and nymphal developments of *G. ochropterus* have been investigated at the two extremely high temperatures.

Embryonic development

The embryonic development period was a mean of 9.7 days at temperature 35°C, significantly longer than at changing temperature 35/25°C (L:D) with a mean of 8.3 days (Tab. 19).

Tab. 19: Mean embryonic developmental period of *Geocoris ochropterus* on cucumber leaves at two high different temperatures

Temperature (±1°C)	n	Embryonic developmental period (days)	
		Mean±SE	Min. - Max.
35	20	9.7±0.1 b	9 - 10
35/25	20	8.3±0.1 a	7 - 9

Means with different small letters indicate significant differences at p≤5% (one-factor ANOVA)

Nymphal development

As shown in Tab. 20, *G. ochropterus* nymphs succeeded to develop into adult stage at constant temperature 35°C and changing temperature 35/25°C, where the total developmental period from N_1 to adult emergence was 17.6-20.1 and 17.9-19.6 days, respectively. Among different instars, N_5 with developmental period ranging 4.5-5.3 days was longer than the other instars except with *T. tabaci* as prey at 35°C, where the mean developmental period was similar between N_1 and N_5 instars. Among different thrips species, the mean total period was significantly longer with *F. occidentalis* as prey (20.1 days) than with *T. tabaci* and *G. ficorum* as prey (18.2 and 17.6 days, respectively) at 35°C. At 35/25°C, the mean total developmental period was shorter with *G. ficorum* as prey (17.9 days) than with *F. occidentalis* (19.1 days) and *T. tabaci* as prey (19.6 days). The mean total developmental period with *F. occidentalis* was significantly longer at 35°C than at 35/25°C within same thrips species. The total period with *T. tabaci* as prey was significantly shorter at 35°C than at 35/25°C. By feeding on *G. ficorum*, the total period of *G. ochropterus* was similar between the two temperatures.

Tab. 20: Mean nymphal developmental period of *Geocoris ochropterus* by feeding on L_2 larvae of *Frankliniella occidentalis* and *Thrips tabaci* on cucumber leaves and *Gynaikothrips ficorum* on *Ficus microcarpa* leaves at two different extremely high temperatures

Temp. (±1°C)	Prey species	n	Developmental period (days)					Total (N_1 to adult) (days) Mean±SE
			N_1 Mean±SE	N_2 Mean±SE	N_3 Mean±SE	N_4 Mean±SE	N_5 Mean±SE	
35	*F. occidentalis*	20	4.8±0.2aA	3.0±0.2aA	3.0±0.2aA	3.9±0.1aA	5.3±0.2aA	20.1±0.3aA
	T. tabaci	20	4.5±0.1abA	2.7±0.1aA	2.8±0.2abA	3.7±0.1aB	4.5±0.2bB	18.2±0.3bB
	G. ficorum	20	4.3±0.2aA	2.6±0.1aA	2.4±0.1bA	3.6±0.1aB	4.6±0.1bB	17.6±0.3bA
35/25	*F. occidentalis*	20	3.9±0.1aB	2.8±0.1aA	2.9±0.2aA	4.1±0.1aA	5.3±0.2aA	19.1±0.2aB
	T. tabaci	20	3.9±0.1aB	3.1±0.2aA	3.2±0.2aA	4.4±0.2aA	5.1±0.2abA	19.6±0.5aA
	G. ficorum	20	3.8±0.1aB	2.7±0.2aA	2.9±0.2aA	4.1±0.2aA	4.5±0.2bA	17.9±0.3bA

Means in columns with different small letters indicate significant differences between different prey species within same predator instars and temperatures, the means with different capital letters indicate significant differences between different temperatures within same predator instars and prey species at $p \leq 5\%$ (two-factor ANOVA).

Mortality

During the nymphal development, the total mortality of *G. ochropterus* was 25, 35 and 30% with *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey at 35°C, respectively (Fig. 46). It was 25, 20 and 25% with *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey at 35/25°C, respectively. In general, the highest mortality occurred in the first instar with 15-20% and 10-20% at 35 and 35/25°C, respectively.

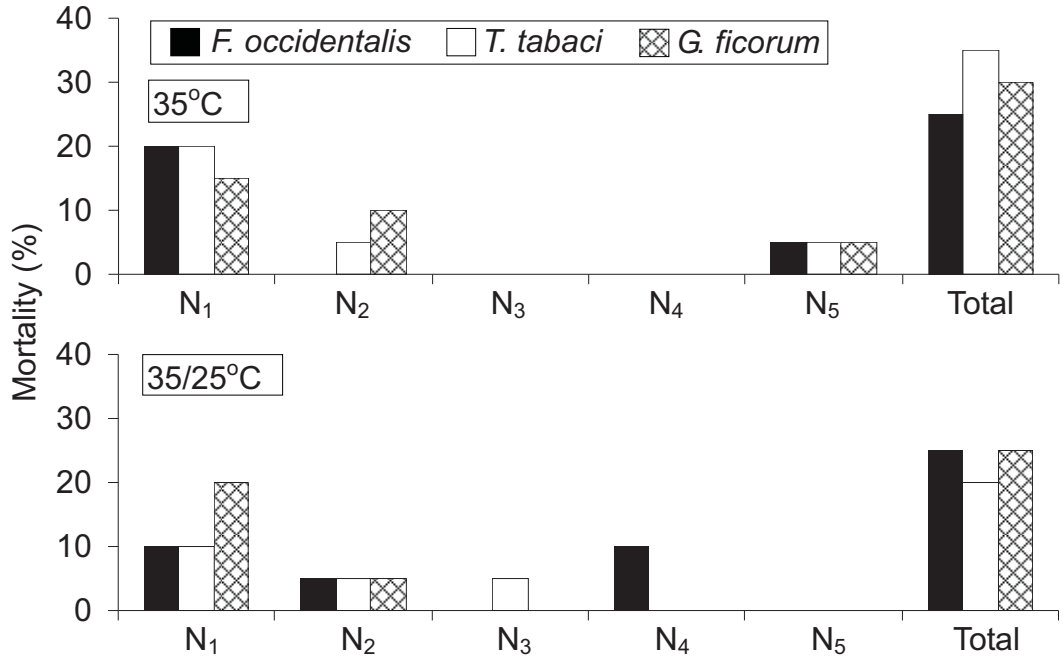

Fig. 46: Percentage mortality of *Geocoris ochropterus* during nymphal development by feeding on L_2 larvae of *Frankliniella occidentalis* and *Thrips tabaci* as prey on cucumber leaves, and *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 35°C and 35/25±1°C

Prey consumption

By feeding on L_2 thrips at 35°C, *G. ochropterus* nymphs consumed a mean of 0.6, 1.9 or 2.0 thrips on the 1st day after hatching with *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey, respectively (Fig. 47). After that, the daily prey consumption increased gradually to reach a peak of 31.7, 41.5 or 20.3 thrips by the N_5 instars on the 19th, 21st and 18th days after hatching with *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey, respectively.

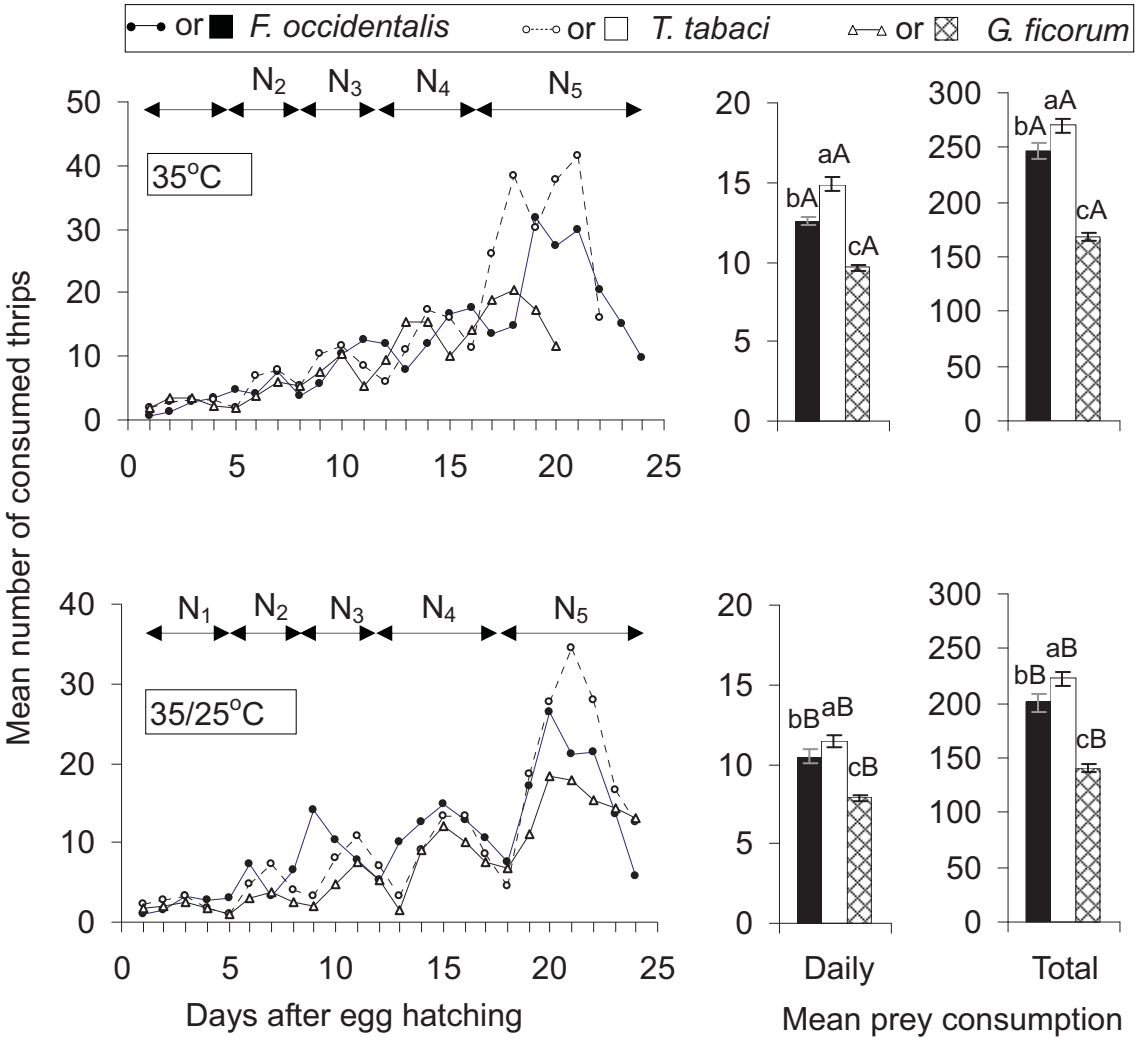

Fig. 47 Mean daily and total prey consumption of *Geocoris ochropterus* during nymphal development with L_2 larvae of *Frankliniella occidentalis* and *Thrips tabaci* on cucumber leaves and *Gynaikothrips ficorum* as prey on *Ficus microcarpa* leaves at temperature 35 and 35/25±1°C. [Bars with different small letters indicate significant difference among the different prey species within same temperature. Bars with different capital letters indicate significant difference between the two temperatures within the same prey species at p≤5% (two-way ANOVA)]

With L_2 thrips as prey at 35/25°C, the daily prey consumption by the nymphs was a mean of 0.9 (*F. occidentalis*), 2.2 (*T. tabaci*) or 1.7 (*G. ficorum*) thrips on the 1st day after hatching. The daily prey consumption increased gradually to reach a peak of 26.5 (*F. occidentalis*), 34.4 (*T. tabaci*) or 18.3 (*G. ficorum*) thrips by the N_5 instars on the 20th, 21st and 20th days.

Throughout the whole nymphal development, the daily prey consumption was averaged 12.6 (*F. occidentalis*), 14.9 (*T. tabaci*) or 9.7 (*G. ficorum*) thrips at 35°C. The daily prey consumption was

a mean of 10.5 (*F. occidentalis*), 11.4 (*T. tabaci*) or 7.9 (*G. ficorum*) thrips at 35/25°C. Among the three thrips species as prey at the same temperature, the mean daily prey consumption was significantly highest with *T. tabaci* as prey, and it was significantly lowest with *G. ficorum* as prey. Moreover, the predatory nymphs daily consumed significantly more thrips at 35°C than at 35/25°C within the same thrips species.

Total prey consumption during the nymphal development was a mean of 246.4 (*F. occidentalis*), 270.2 (*T. tabaci*) or 168.9 (*G. ficorum*) thrips at 35°C. It was a mean of 200.6 (*F. occidentalis*), 222.5 (*T. tabaci*) or 141.4 (*G. ficorum*) thrips at 35/25°C. Within the same temperature, the mean total prey consumption was significantly highest with *T. tabaci* as prey, and it was significantly lowest with *G. ficorum* as prey. Within the same thrips species, the mean total prey consumption was significantly higher at 35°C than at 35/25°C.

3.1.6 Effect of extremely low temperature on survival of *Geocoris ochropterus* in different life stages

G. ochropterus could not move and feed under the extremely low temperature 3 and 6°C. But its activity could recover at room temperature if it did not die. The survival rate of the predator decreased as they had been kept for a longer time at the low temperatures (Fig. 48). Moreover, the survival rate of eggs, nymphs and male adults decreased more rapidly than that of female adults.

At temperature 3°C, the survival rate of eggs and N_3 nymphs decreased from 86.7-100.0% on the 3rd day after treatment to 3.3-20.0% on the 30th day and 0.0% on the 45th day. Male adults survived 90.0% on the 3rd day after treatment, 10.0% on the 60th day and 0.0% on the 75th day after treatment. The adult females of *G. ochropterus* were found to survive 5.0% on the 75th day after treatment.

At temperatures 6°C, the eggs and N_3 nymphs of *G. ochropterus* decreased to 0.0% in 60 days. The adult males still survived 5.0% in 75 days under the low temperature. The adult females exhibited higher tolerance to low temperature than the males. On the 90th day after treatment, the females survived 5.0%, while the adult males all died.

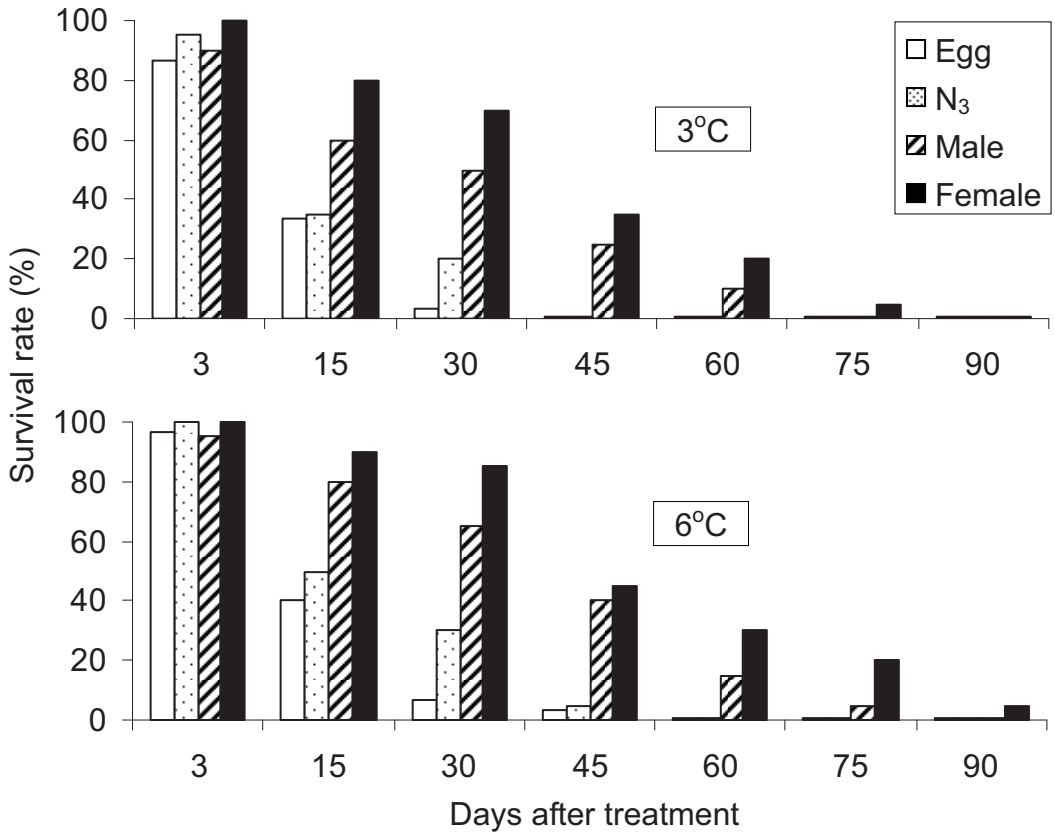

Fig. 48: Percentage survival rate of *Geocoris ochropterus* in life stages of egg, N_3 instar, adult male and female after keeping for different time at two low temperature 3 and 6°C.

3.1.7 Prey preference by *Geocoris ochropterus*

3.1.7.1 Prey-age preference

Figure 49 indicates the preference by *G. ochropterus* for different life stages of thrips as prey. When L_1 and L_2 as well as adult females of each thrips species were simultaneously offered as prey, predatory N_2 nymphs have no prey preference for life stages of *F. occidentalis* within first 3 days during the stage. After that, the predatory nymphs came to prefer adult over the larval thrips. The mean number of consumed thrips on each of the 5 experimental days ranged 1.3-2.9 adult, 0.9-1.1 L_2 and 1.0-1.2 L_1 thrips/N_2 nymph. The predatory N_2 nymphs also preferred adult to the larvae of *T. tabaci*, where they daily consumed 1.9-2.5 adult, 0.9-1.2 L_2 and 0.5-0.9 L_1 thrips/ N_2 nymph. However, with *G. ficorum* as prey, the predatory N_2 nymphs preferred the larvae to the adult prey, where they daily consumed 0.2-0.7 adult, 0.7-1.4 L_2 and 0.9-1.9 L_1 thrips/N_2 nymph.

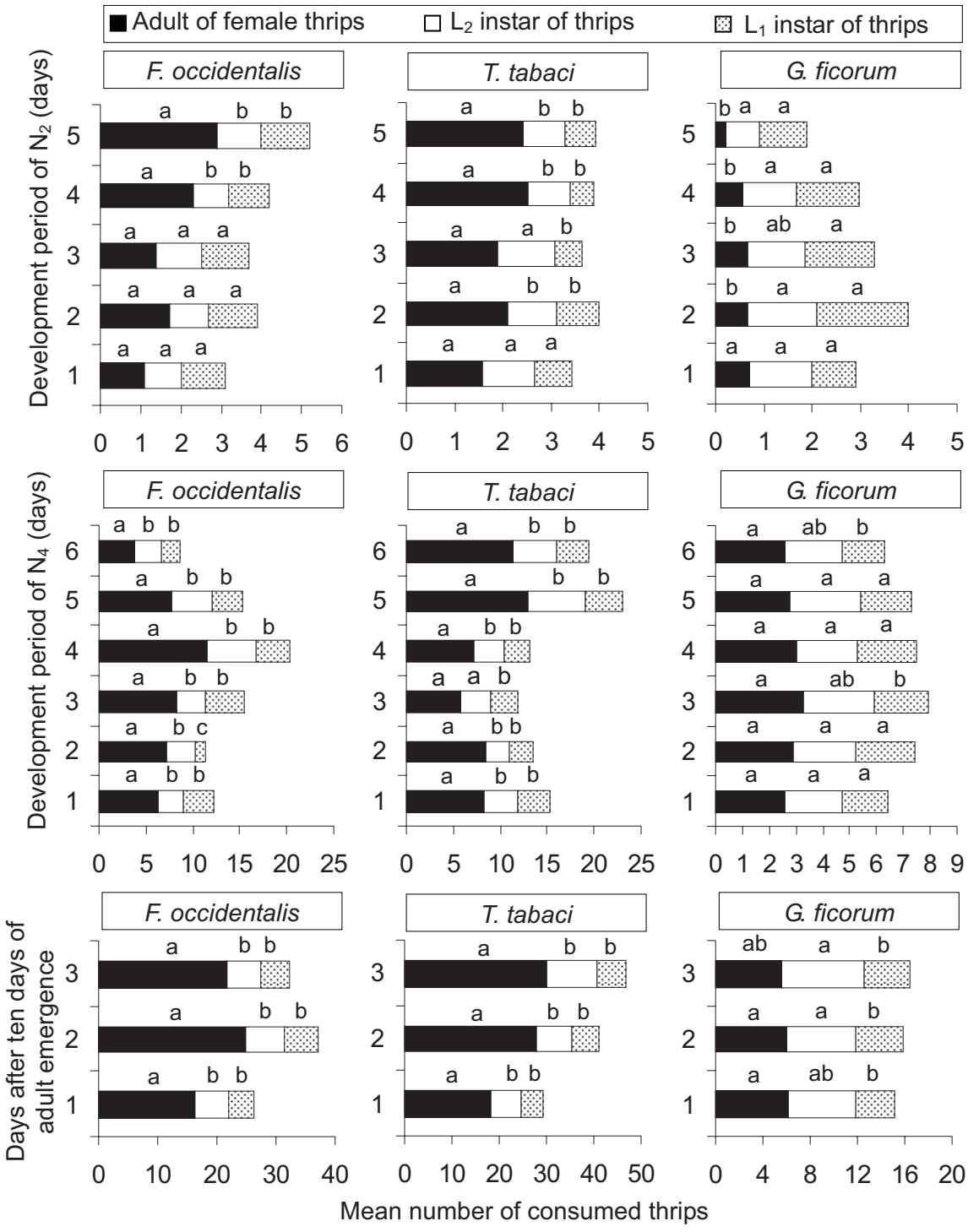

Fig. 49: Prey consumption by N_2, N_4 nymphs and 10-day-old adult females of *Geocoris ochropterus* with L_1, L_2 and adult females of *Frankliniella occidentalis*, *Thrips tabaci* and *Gynaikothrips ficorum* as prey at temperature 25±1°C. [Different letters within the same bar indicate significant difference in the prey consumption of the different prey stages at p≤5% (one-factor ANOVA)].

Predatory N_4 nymphs also preferred the adult over the larvae of *F. occidentalis* and *T. tabaci*. The predators daily consumed 3.8-11.6 adult, 2.8-5.1 L_2 and 1.2-3.2 L_1 thrips/N_4 nymph with *F. occidentalis* as prey. The daily prey consumption of *T. tabaci* by N_4 *G. ochropterus* was 5.8-12.9 adult, 2.6-6.1 L_2 and 2.4-4.1 L_1 thrips/N_4 nymph. No preference for the 3 life stages of *G. ficorum* was showed in N_4 nymphs during most days. N_4 nymphs consumed daily 5.8-12.9 adult, 2.6-6.1 L_2 and 2.4-4.1 L_1 *G. ficorum* as prey.

Ten-day-old adult females of *G. ochropterus* preferred significantly more the adult than the larvae of *F. occidentalis* and *T. tabaci*. The females daily consumed 18.1-30.1 adult, 6.5-10.6 L_2 and 4.8-6.1 L_1 *F. occidentalis*. It daily consumed 18.1-30.1 adult, 6.5-10.6 L_2 and 4.8-6.1 L_1 *T. tabaci*. When *G. ficorum* was tested as prey, the adult and L_2 larvae were more preferred than the L_1 larvae by the female *G. ochropterus*. The daily prey consumption of *G. ochropterus* female was 2.6-3.3 adult, 2.1-2.6 L_2 and 1.6-2.2 L_1 *G. ficorum*.

3.1.7.2 Prey-species preference

As shown in Fig. 50, *G. ochropterus* of all tested life stages significantly preferred *T. tabaci* (♀♀) and *F. occidentalis* (♀♀) to *T. urticae* (♀♀), *B. tabaci* (puparia) and *A. gossipii* (1-2 days old). N_2 nymphs of *G. ochropterus* showed significantly higher preference for *T. tabaci* over *F. occidentalis*. N_2 nymphs consumed daily 2.2-3.7 *T. tabaci* and 1.2-2.8 *F. occidentalis*. At the same time, the other pest species were consumed 0.5-1.7 *T. urticae*, 0.3-1.1 *B. tabaci* and 0.1-0.2 *A. gossipii*.

When the predator was in N_4 nymph, it showed similar preference for the both thrips species, consuming 4.6-7.9 thrips. Meanwhile it daily consumed 2.5-4.3, 0.4-0.5 and 0.2-0.8 individuals from *T. urticae*, *B. tabaci* and *A. gossipii*, respectively.

Ten-day-old female adults of *G. ochropterus* preferred *T. tabaci* to *F. occidentalis*. The predatory female adults also consumed daily 9.0-9.9, 8.7-9.7, 4.7-6.1, 0.0-0.1 and 0.2-1.4 individuals from *T. tabaci*, *F. occidentalis*, *T. urticae*, *B. tabaci* and *A. gossypii*, respectively.

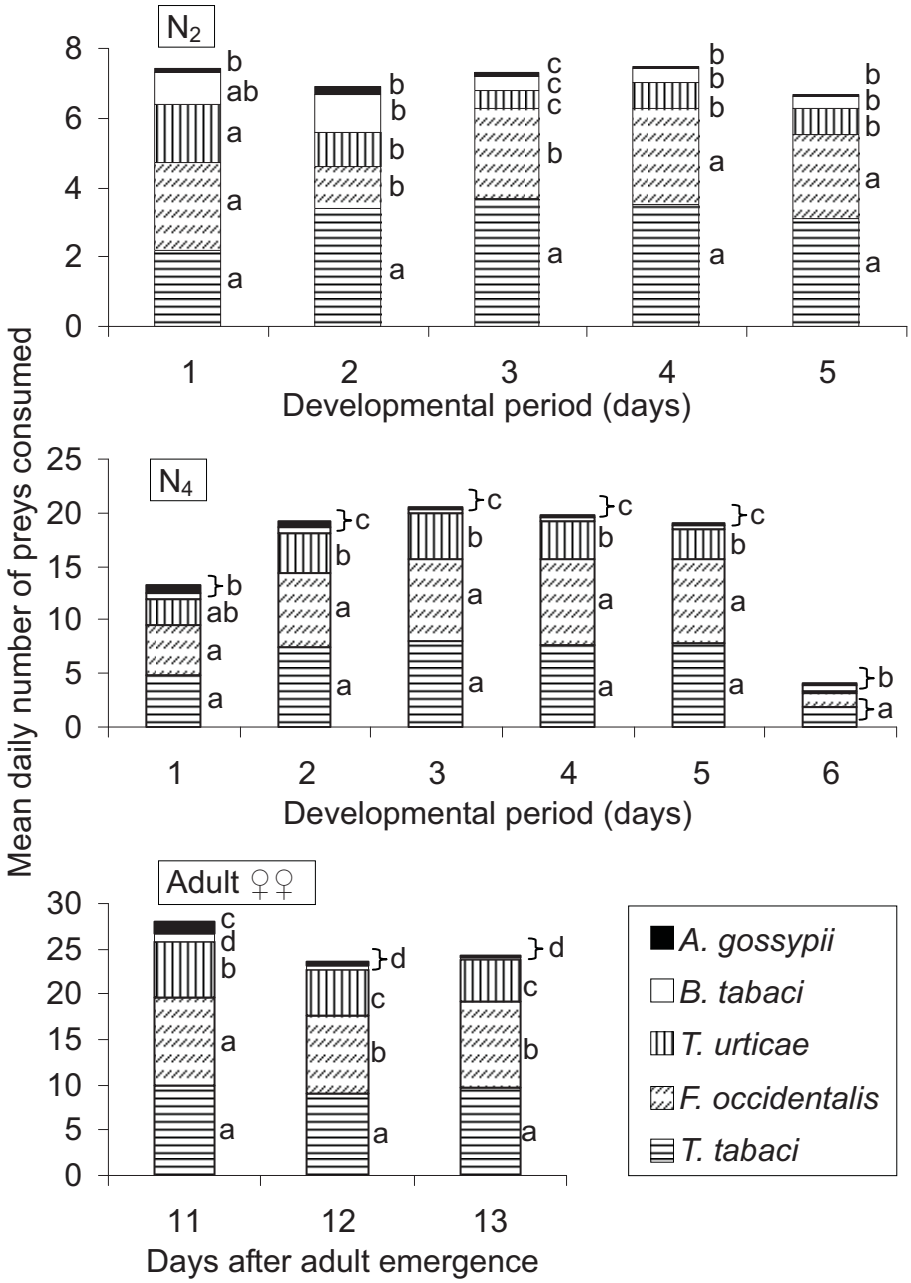

Fig. 50: Prey consumption by N_2, N_4 instars and 10-day-old adult females of *Geocoris ochropterus* by feeding on mixed population of 5 different prey species offered together on cucumber leaves at 25±1°C temperature [Different small letters within the same bar indicate significant differences in the prey consumption of the different prey species at $p \leq 5\%$ (one-factor ANOVA)].

3.1.8 Effect of the different nutritions on *Geocoris ochropterus*

The survival period of N_4 instar and adult of *G. ochropterus* have been investigated at different nutrition conditions: (A) no leaf + no prey, (B) leaf + no prey, (C) no leaf + *T. tabaci*, (D) leaf + *B. tabaci* (E) leaf + *T. tabaci*, (F) only 10% honey emulsion.

Effect on the N_4 instar

Survival period, mortality and developmental period of the 4th instar (N_4) of *G. ochropterus* at different nutrition conditions are showed in Fig. 51.

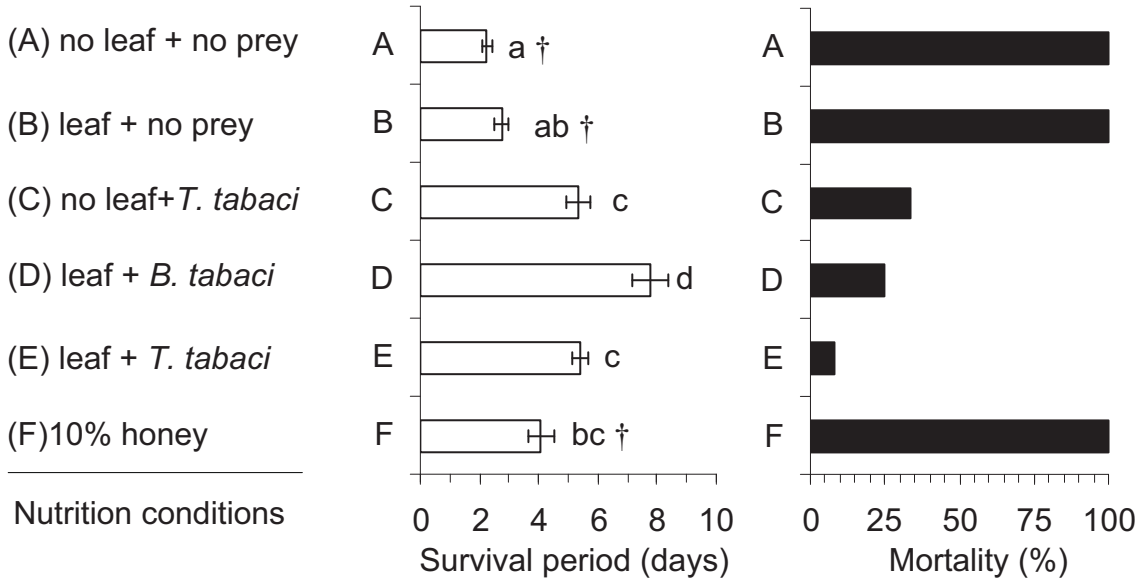

Fig. 51: Mean survival periods and mortalities of freshly molted N_4 nymphs of *Geocoris ochropterus* by feeding on different nutrition conditions at temperature 25±1°C [Bars with different letters are significantly different at p≤5% (one–factor ANOVA). "†" represents the nymphs failed to complete development]

N_4 nymphs of *G. ochropterus* lived in a mean of 4.1 days at 10% honey emulsion (F), significantly longer than that at nutrition A, but similar to that at nutrition B. However, all individuals of N_4 nymphs of *G. ochropterus* failed to develop into next instar, leading to mortality of 100%. At nutrition conditions of C (no leaf + *T. tabaci*), D (leaf + *B. tabaci*) and E (leaf + *T. tabaci*) which containing pest insects as prey: the freshly molted N_4 nymphs of *G. ochropterus* at all these three nutrition conditions could develop into next instar, with mortality of 33.3, 25.0 and 8.3 % among the predatory nymphs at C, D and E nutrition conditions, respectively.

Effect on the adult

Adult females (♀♀) and males (♂♂) of *G. ochropterus* lived significantly longer at the nutrition conditions with pest insects as prey than without prey (Fig. 52). In the case of prey presence, the survival periods at C (no leaf + *T. tabaci*) and E (leaf + *T. tabaci*) were similar, ranging from 54.5 to 58.7 days for ♀♀, and 43.6-49.6 days for ♂♂. It was significantly longer than the period at D (leaf + *B. tabaci*), where a mean survival period of 35.8 and 26.7 days were record for ♀♀ and ♂♂, respectively. However, in the case of no prey, the survival periods at F (10% honey) was 14.8 and 10.3 days for ♀♀ and ♂♂, respectively. It was significantly longer than that at A (no leaf + no prey) and B (leaf + no prey), where the period was 4.3-8.8 days.

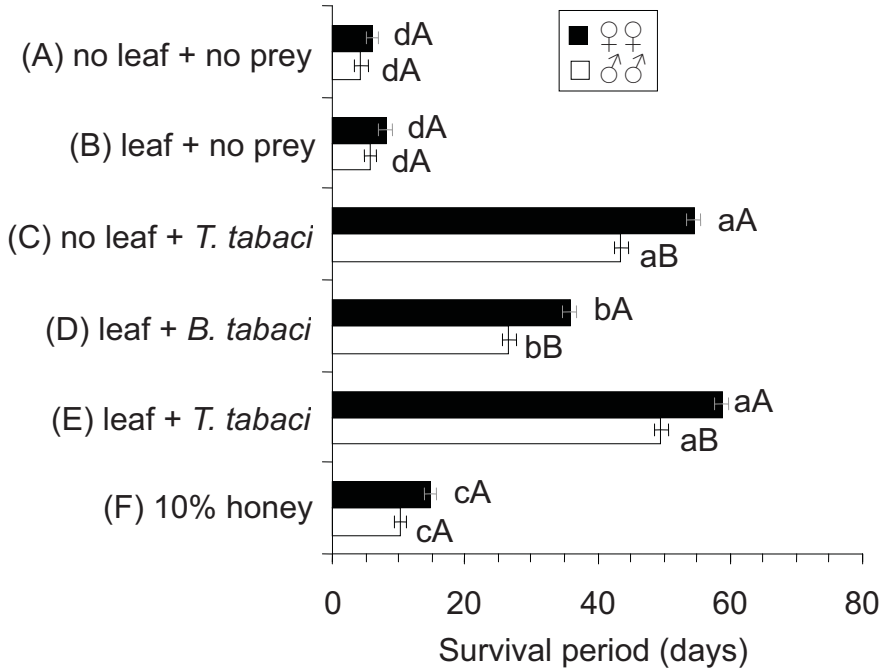

Fig. 52: Mean survival periods of 2-day-old female and male adults of *Geocoris ochropterus* by feeding on different nutrition conditions at 25±1°C. [Bars with different small letters are significantly different within same sexes. Bars with capital letters are significantly different within same nutrition condition at p≤5% (two-factor ANOVA)]

3.1.9 Cannibalism of *Geocoris ochropterus*

Cannibalism of *G. ochropterus* was investigated at in the absence and presence of prey.

In the absence of prey

In the absence of prey, there was cannibalism (CANN) in 55% of the tests between different life stages of *G. ochropterus* (Fig. 53). When the CANN occurred, female adult always attacked individual of other life stages, even male adult. Among all life stages, egg was most vulnerable to female adult. CANN occurred in every pair of female adult vs. egg (CL=100.0%), where proportion of consumed eggs among every mass were averaged 69.3%. N_3 instar was the second most vulnerable life stage, where 66.7% nymphs were killed. Male adults were also killed by 33.3% when they were exposed to female adults without other pest insects offered as prey.

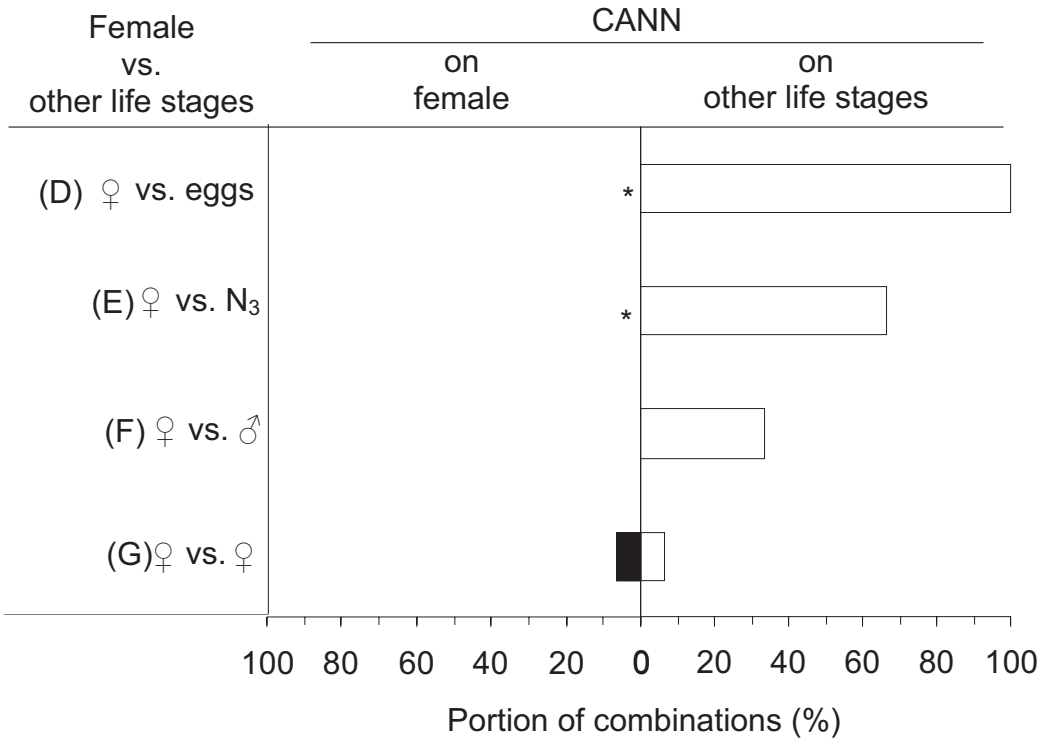

Fig. 53: Cannibalism (CANN) between different life stages of *Geocoris ochropterus* in the absence of L_2 *Thrips tabaci* as prey at temperature 25±1°C. [The black bars represent the percentage portion of combinations with female adults of *G. ochropterus* killed. The white represent the combinations with other individuals killed. Asterisks indicate significant asymmetry for that combination of predators (χ^2, df = 2, p≤5%)]

In the presence of prey

With *T. tabaci* offered as prey, there was cannibalism (CANN) in 6.7% of the tests between different life stages of *G. ochropterus* (Fig. 54). Only 20.0% of eggs and 6.7% of N_3 nymphs were attacked when they were exposed to female adults. The asymmetrical interactions between female adult vs. egg and female adult vs. N_3 nymphs were not significant.

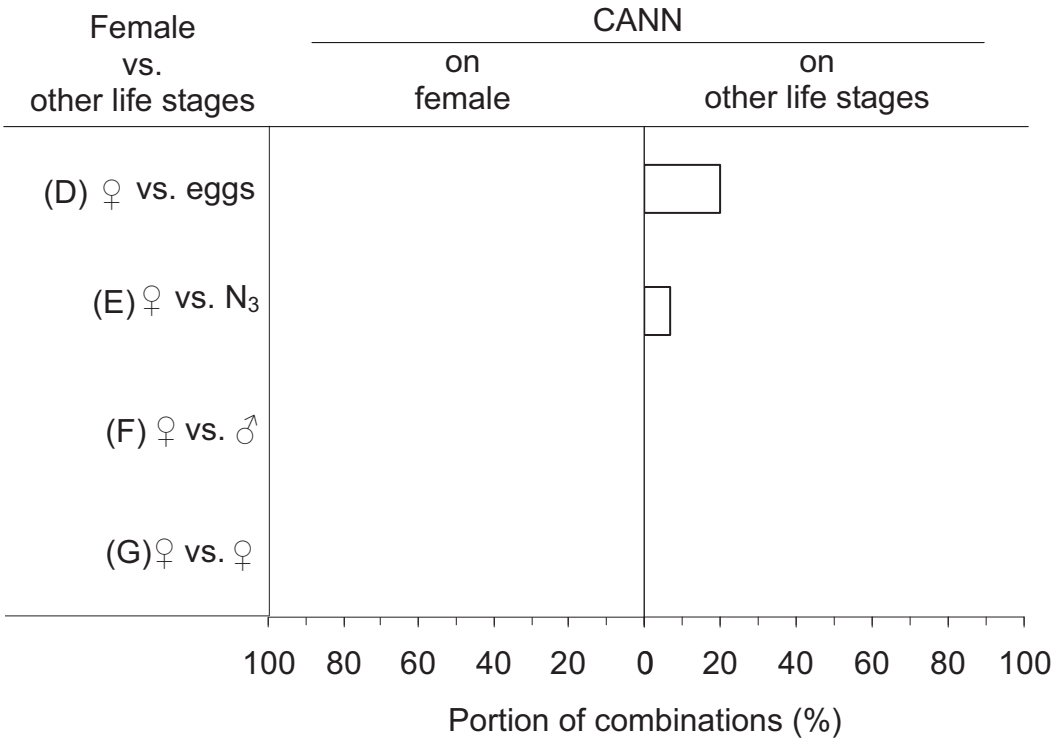

Fig. 54: Cannibalism (CANN) between different life stages of *Geocoris ochropterus* in the presence of L_2 *Thrips tabaci* as prey at temperature 25±1°C. [The black bars represent the percentage portion of combinations with female adults of *G. ochropterus* killed. The white represent the combinations with other individuals killed. Asterisks indicate significant asymmetry for that combination of predators (χ^2, df = 2, p≤5%)]

The percentage portion of eggs consumed by female adult significantly decreased from 69.3% (CL=100.0%) in the absence of thrips to 4.0% (CL=20%) in the presence of thrips (Fig. 55). The portion of consumed N_3 nymphs and male adults significantly decreased from 66.7% and 33.3% in the absence of thrips to 6.7% and 0.0% in the presence of thrips, respectively.

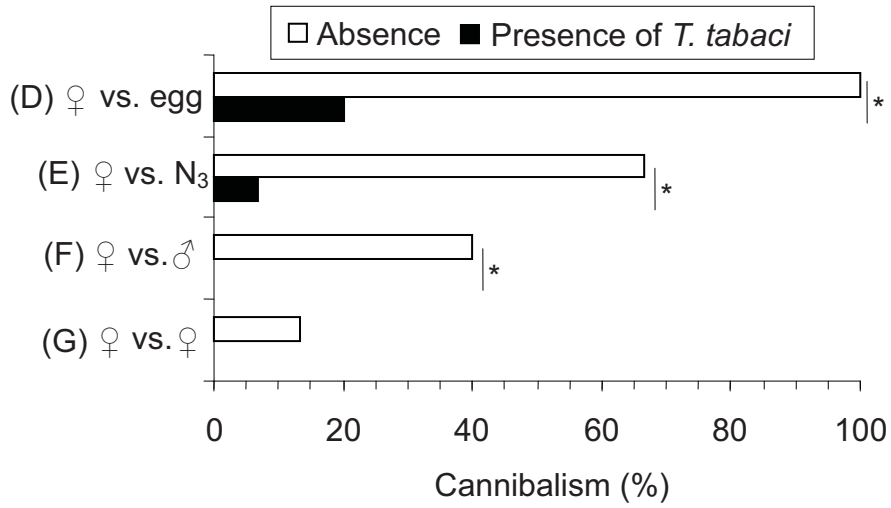

Fig. 55: Percentage cannibalism between different life stages of *Geocoris ochropterus* in absence and presence of L_2 *Thrips tabaci* as prey at temperature 25±1°C. [Bars represent the percentage of combination where one predator was killed, with white bars for the absence of prey and black bars for the presence of prey. Percentages followed by an asterisk are significantly different (χ^2, df = 2, p≤5%)]

As shown in Fig. 56, the number of consumed *T. tabaci* in the arenas of B (1 ♂) and C (1♀) was average 21.8-29.1 thrips. In the arenas of F (1♀ vs. 1♂) and G (1♀ vs. 1♀), the number of consumed *T. tabaci* ranged average from 34.8 to 38.3 thrips. This indicated that the predatory adults showed additive effect to each other.

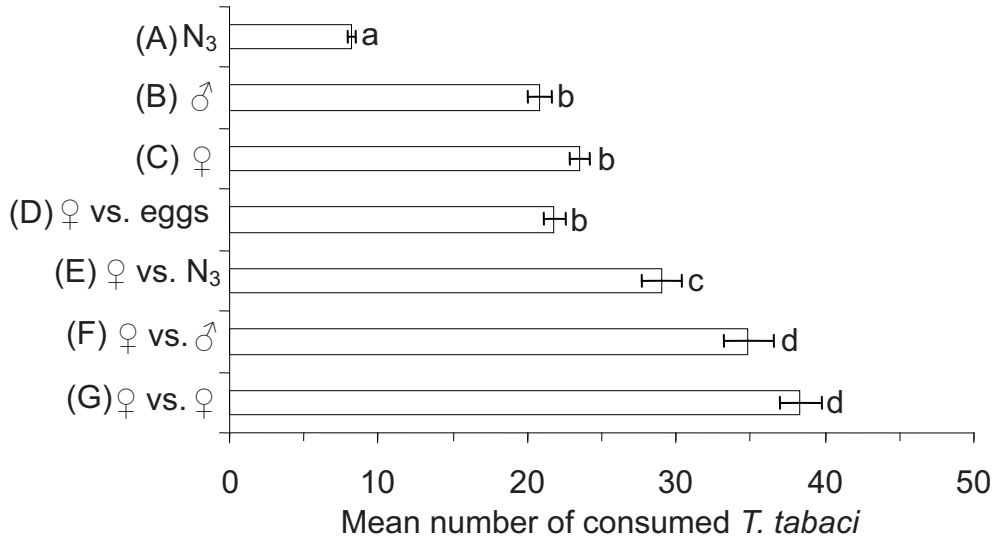

Fig. 56: Mean number of consumed L_2 *Thrips tabaci* as prey by different life stages of *Geocoris ochropterus* in each combination at 25±1°C temperature. [Bars with different letters are significantly different at p≤5% (one-way ANOVA)]

3.1.10 Intraguild predation between *Geocoris ochropterus* and *Orius similis*

The intraguild predateion between *G. ochropterus* and *O. similis* was determined in the absence and presence of prey.

In the absence of prey

Fig. 57 demonstrated that there was no IGP in 38.3% of the tests between *G. ochropterus* and *O. similis* in the absence of prey. When the IGP occurred, female adult of *G. ochropterus* always freed from attack by *O. similis*. Instead, it killed 66.7% of N_3 nymphs and 46.7% of female adults of *O. similis*. In the pairs of F (N_3 nymph of *G. ochropterus* vs. female adult of *O. similis*), both predatory species attacked each other without significant asymmetry. *G. ochropterus* eggs were vulnerable to female adult of *O. similis*, with a mean of 30.7% eggs were killed from a mass in each pair (IL=86.7%).

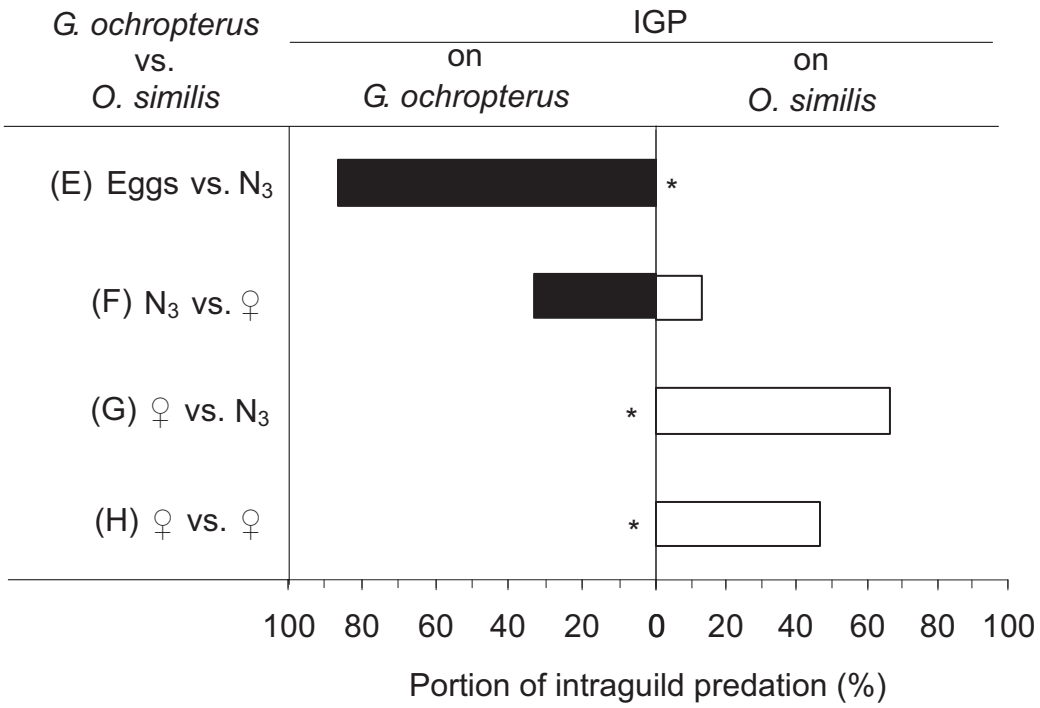

Fig. 57: Intraguild predation (IGP) between different life stages of *Geocoris ochropterus* and *Orius similis* in the absence of *Thrips tabaci* as prey at temperature 25±1°C. [The black bars represent the percentage portion of combinations with *G. ochropterus* killed. The white represent the combinations with *O. similis* killed. The bars with scattered points represent the combinations without IGP recorded. Asterisks indicate significant asymmetry for that combination of predators (χ^2, df = 2, p≤5%)]

In the presence of prey

With *T. tabaci* offered as prey, there was no IPG in 73.3% of the tests between *G. ochropterus* and *O. similis* (Fig. 58). Interaction between the two predatory bug species was not significantly asymmetry, except for egg of *G. ochropterus* vs. female adult of *O. similis*.

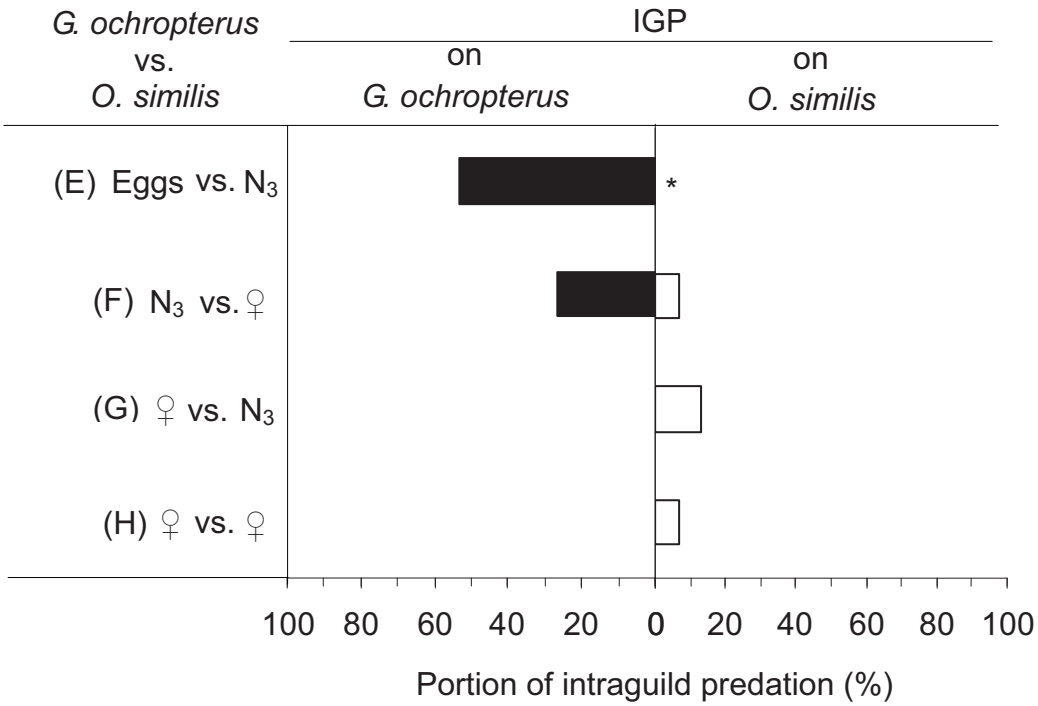

Fig. 58: Intraguild predation (IGP) between different life stages of *Geocoris ochropterus* and *Orius similis* in the presence of *Thrips tabaci* as prey at temperature 25±1°C. [The black bars represent the percentage portion of combinations with *G. ochropterus* killed. The white represent the combinations with *O. similis* killed. The bars with scattered points represent the combinations without IGP recorded. Asterisks indicate significant asymmetry for that combination of predators (χ^2, df = 2, p≤5%)]

The percentage portion of eggs of *G. ochropterus* consumed by female adult of *O. similis* significantly decreased from 30.7% (IL=86.7%) in the absence of thrips to 12.0% (IL=53.3%) in the presence of thrips (Fig. 59).

As shown in Fig. 60, the number of consumed *T. tabaci* was a mean of 24.9 thrips for the combination H (1 *G. ochropterus* ♀ vs. 1 *O. similis* ♀). It was significantly higher than that in D

(1 *G. ochropterus* ♀) and G (1 *G. ochropterus* ♀ vs. 1 *O. similis* N_3). This indicated an additive effect between the female adults of *G. ochropterus* and *O. similis*. While combined presence of *G. ochropterus* ♀ and *O. similis* N_3, or *G. ochropterus* N_3 and *O. similis* ♀, did not show additive effect.

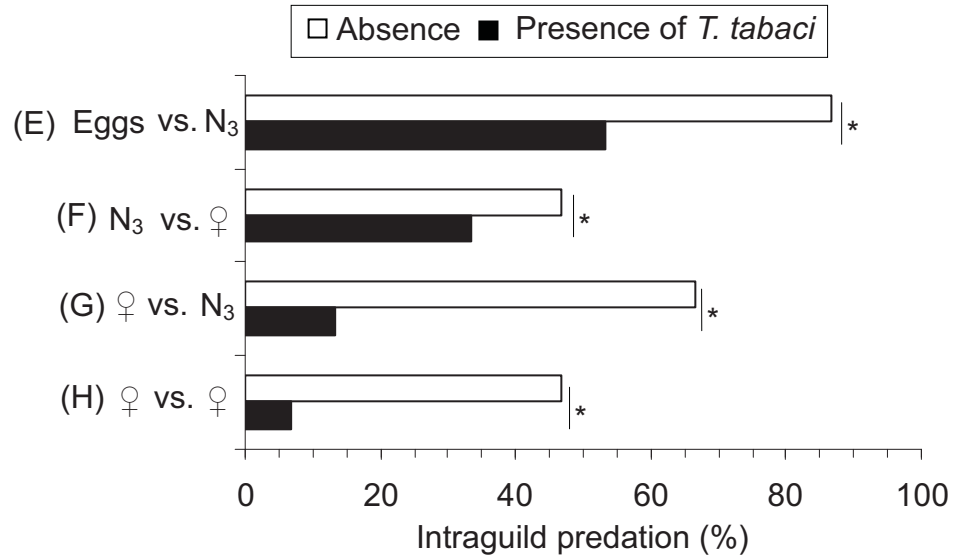

Fig. 59: Percentage intraguild predation between different life stages of *Geocoris ochropterus* and *Orius similis* in the absence and presence of L_2 *Thrips tabaci* at 25±1°C. [Bars represent the percentage of combination where one predator was killed, with white bars for the absence of thrips and black bars for the presence of thrips. Percentages followed by an asterisk are significantly differentχ^2, df = 2, p≤5%)]

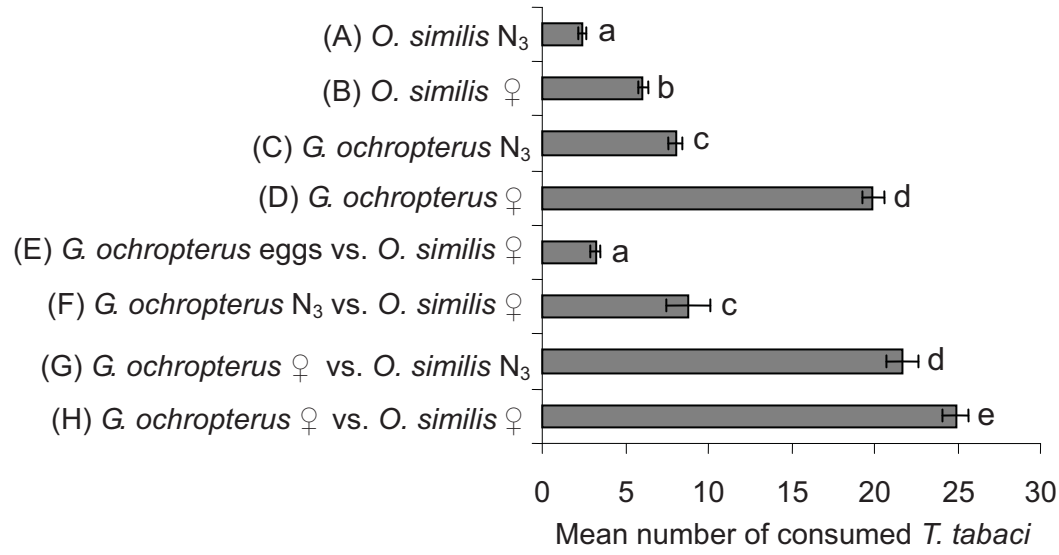

Fig. 60: Mean number of consumed L_2 *Thrips tabaci* as prey by different life stages of *Geocoris ochropterus* and *Orius similis* at temperature 25±1°C. [Bars with different letters are significantly different at p≤5% (one-way ANOVA)]

3.2 Greenhouse experiments

3.2.1 Efficiency of *Geocoris ochropterus* against *Frankliniella occidentalis*

In experiment I, where the adults of *G. ochropterus* were introduced one week after the plant of sweet pepper had been infested with *F. occidentalis*, the mean total number of *F. occidentalis* from the first instar to adult was 83.0 thrips/plant in the 1st week after infestation (Fig. 61). It continued to increase until it reached a maximum of 185.3 thrips/plant in the 3th week. Afterwards, it decreased continuously till it reached a mean of 41.7 thrips/plant in the last experimental week.

In experiment II, the mean total number of the thrips from the firs instar to adult was 72.7 thrips/plant in the 1st week. It continuously increased and reached a maximum of 300.3 thrips/plant in the 3th week. From then on, the population of *F. occidentalis* decreased till it reached 88.3 thrips/plant in last experimental week.

However in the case of experiment III, where no predator were released, the mean total number of the thrips from the first instar to adult was 78.3 thrips/ plant in the 1st week after infestation, and it continued to increase till it reached a maximum of 654.0 thrips/plant in the 4th week, after that it continuously declined till it reached 529.0 thrips/plant.

The mean number of *F. occidentalis* from the first instar to adult was significantly higher in the experiment III than in the other two experiments after one week of predator releasing. The mean number in experiment II was significantly higher than that in experiment I since the 2nd week of infestation of the thrips.

G. ochropterus was able to successfully feed, reproduce and establish on pepper under greenhouse conditions with *F. occidentalis* as prey. The total number of *G. ochropterus* of different life stages increased gradually. In experiment I, the mean number of *G. ochropterus* was 2.0 adults and 11.3 eggs per plant in the 3th week after thrips infestation, and it reached a mean of 3.7 adults, 17.7 eggs and 20.3 nymphs per plant in the last experimental week. In experiment II, the number of *G. ochropterus* was 2.0 adults and 6.7 eggs per plant in the 3th week. In the last week, its population was 1.7 adults, 17.7 eggs and 17.0 nymphs per plant.

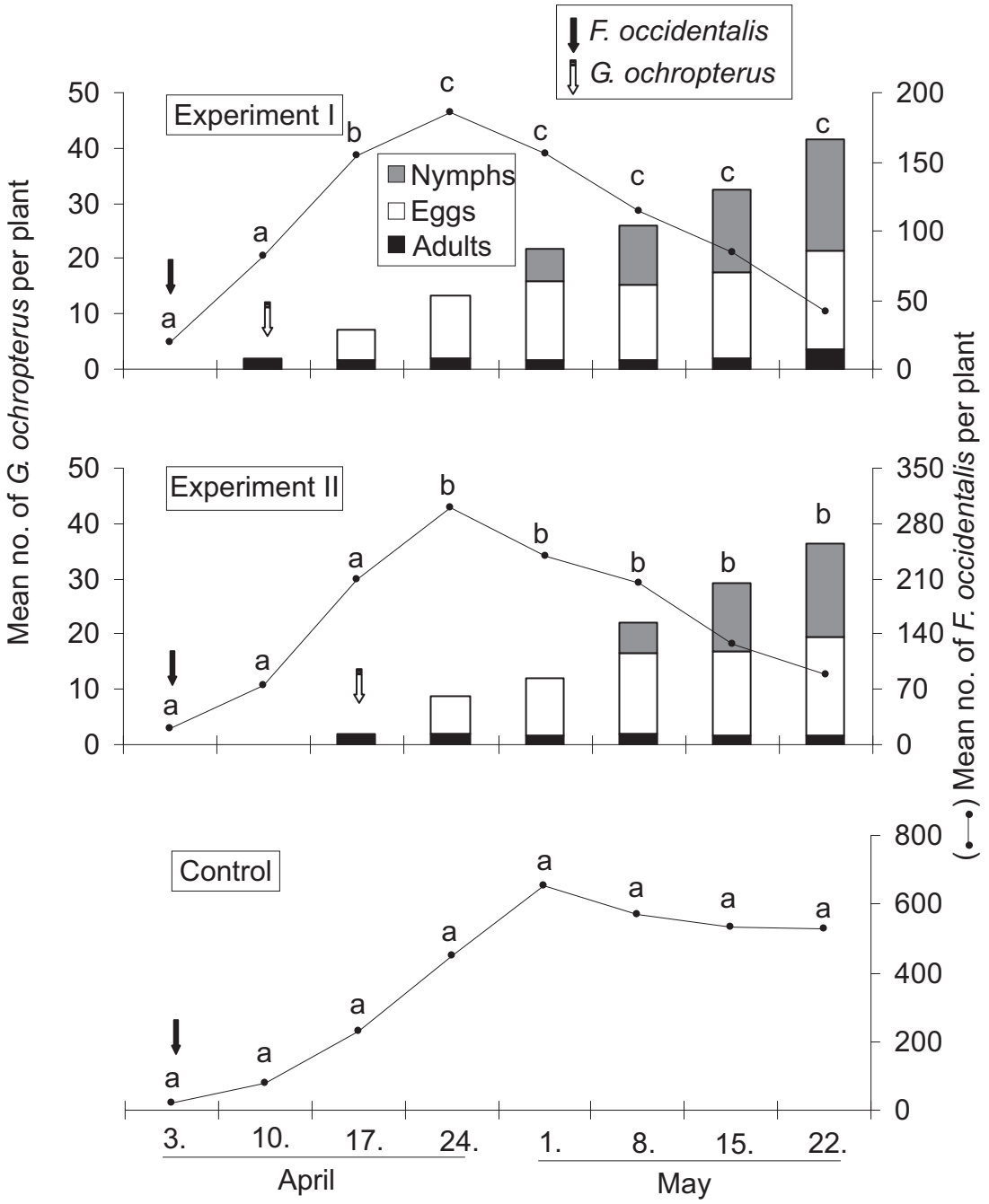

Fig. 61: Mean numbers of *Geocoris ochropterus* (adult, nymph and egg stages) and *Frankliniella occidentalis* (all stages) per sweet pepper plant one week (experiment I) and two weeks (experiment II) after releasing as well as the control experiment in greenhouse. [Different letters indicate significant differences in the mean numbers of *F. occidentalis* within the same week in the three different experiments at $p \leq 5\%$ (one-factor ANOVA)]

Figure 62 presents the percentage reduction of *F. occidentalis* population in experiment I and II in comparison with the control experiment. The reduction of *F. occidentalis* population was 32.3% one week after *G. ochropterus* release in experiment I. The reduction of thrips population increased generally with a value of 58.7% in the 2nd week and 79.9% in the 4th week after *G. ochropterus* release. Maximum reduction of 92.1% in *F. occidentalis* population was achieved in experiment I in the last experimental week. In experiment II, where the predator was released 2 weeks after thrips infestation, the percentage reduction in the thrips population was 33.0% in the 1st week after the release of the predator, and 63.8% in the 2nd week. The reduction in the thrips population in cabin II reached its maximum in the last experimental week, where it was 83.3%.

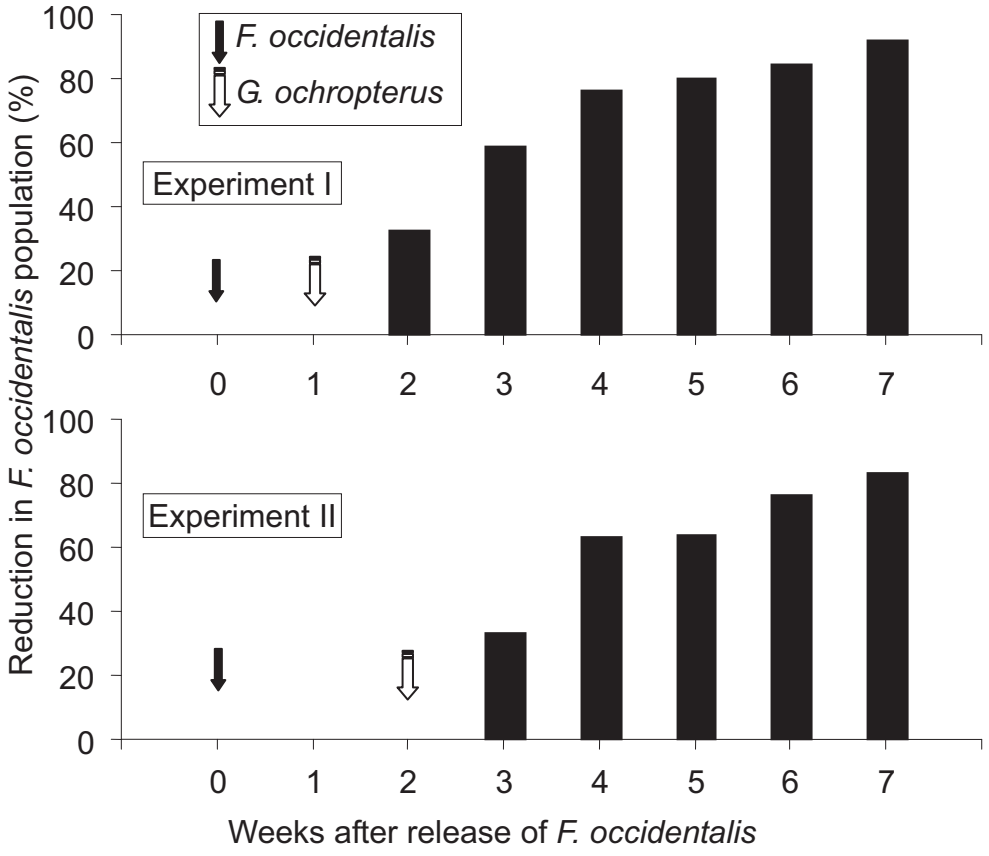

Fig. 62: Percentage reduction in *Frankliniella occidentalis* population on sweet pepper plants compared with the control experiment after one week (experiment I) and two weeks (experiment II) of *Geocoris ochropterus* release in greenhouse

3.2.2 Efficiency of *Geocoris ochropterus* against *Thrips tabaci*

Figure 63 shows the results of greenhouse experiments on biological control of *T. tabaci* by using *G. ochropterus*.

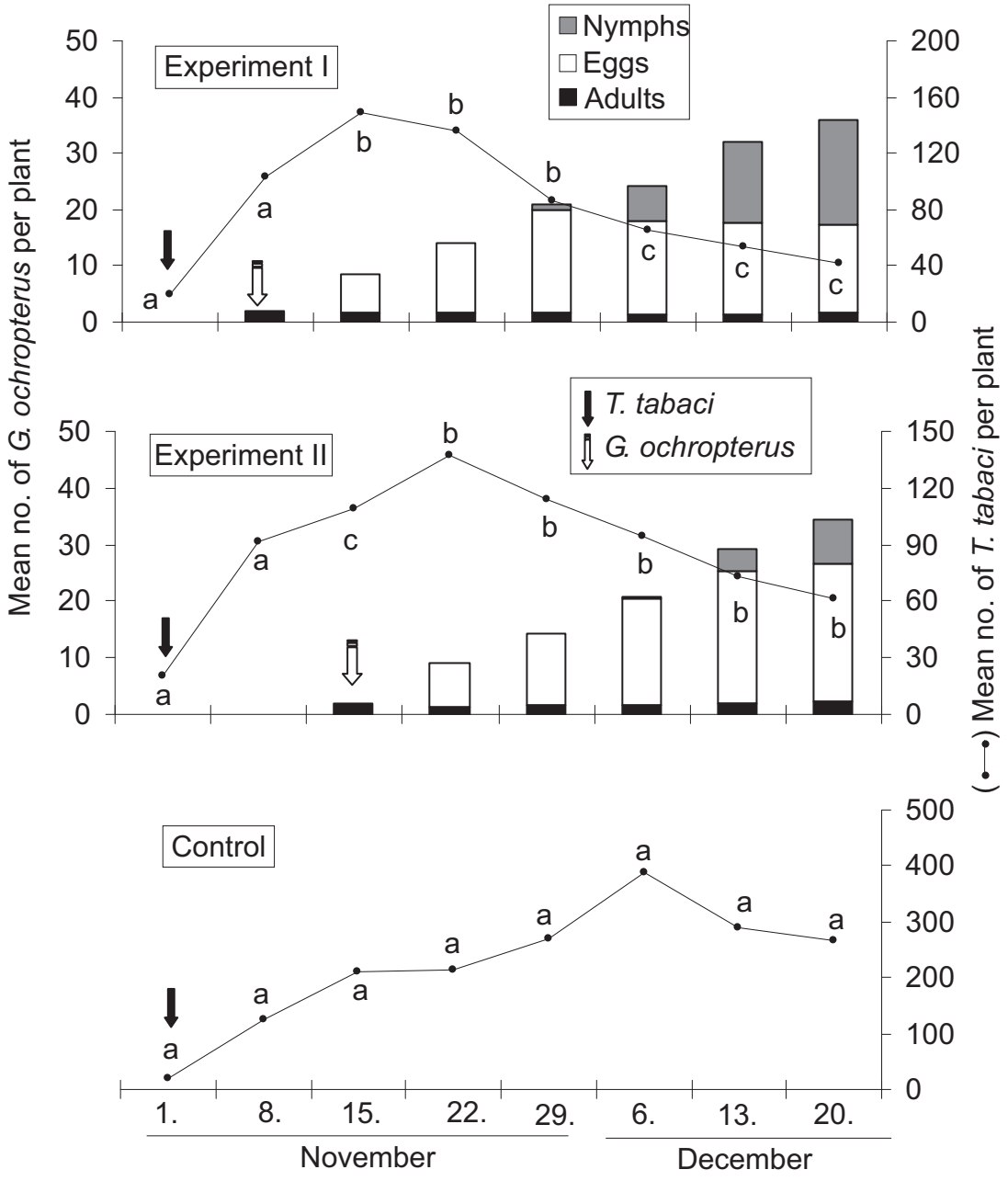

Fig. 63: Mean numbers of *Geocoris ochropterus* (adult, nymph and egg stages) and *Thrips tabaci* (all stages) per sweet pepper plant one week (experiment I) and two weeks (experiment II) after releasing as well as the control experiment in greenhouse. [Different letters indicate significant differences in the mean numbers of *T. tabaci* within the same week in the three different experiments at $p \leq 5\%$ (one-factor ANOVA)]

In experiment I, the total number of *T. tabaci* from 1st instar to adult was a mean of 103.7 thrip/plant in the 1st week after infestation. The mean number continuously increased till it reached a maximum of 149.0 thrips/plant in the 2nd week. Then the population of *T. tabaci* gradually decreased to 41.3 thrips/plant in the last experimental week.

The mean number of *T. tabaci* in experiment II was 92.0 thrips/plant in the 1st week after infestation, and increased gradually to a maximum of 137.3 thrips/plant in the 3rd week. Afterward, it decreased gradually till it reached a mean of 61.7 thrips/plant in last week of the experiment. The number of *T. tabaci* from 1st instar to adult was significantly higher in experiment II than in experiment I since 5th week after *T. tabaci* infection.

The number of thrips in the control experiment (III) was in general significantly higher than both other experiments, where it increased continuously from a mean of 125.0 thrips/plant in the 1st week after infestation to 387.7 thrips/plant in the 5th week. It had taken hereafter a declining tendency where it reached a mean of 266.0 thrips/plant in the last experimental week.

The population of *G. ochropterus* in experiment I was a mean of 1.7 adults, 18.3 eggs and 1.0 nymph per plant in the 4th week after thrips infestation, and increased to reach 1.7 adult, 15.7 eggs and 18.7 nymphs per plant in the last week of the experiment. In experiment II, the number of *G. ochropterus* was in the 4th week 1.7 adults and 12.7 eggs per plant. It took hereafter an increasing tendency where it valued per plant in mean 2.3 adults, 24.3 eggs and 7.7 nymphs in the last week of the experiment.

As illustrated in Fig. 64, the percentage reduction of *T. tabaci* population was 29.4% one week after *G. ochropterus* release in experiment I. The reduction increased generally with 68.2% in the 3rd week and 81.6% in 5th week. Maximum reduction of 85.7% in *T. tabaci* population was achieved in experiment I in the 6th week. In experiment II, where the predator was released 2 weeks after infestation with *T. tabaci*, the percentage reduction in the thrips population was 35.4% in the 1st week after the predator release, and 75.7% in the 3rd week. The reduction in the thrips population in experiment II reached a maximum of 76.8% in the last experimental week.

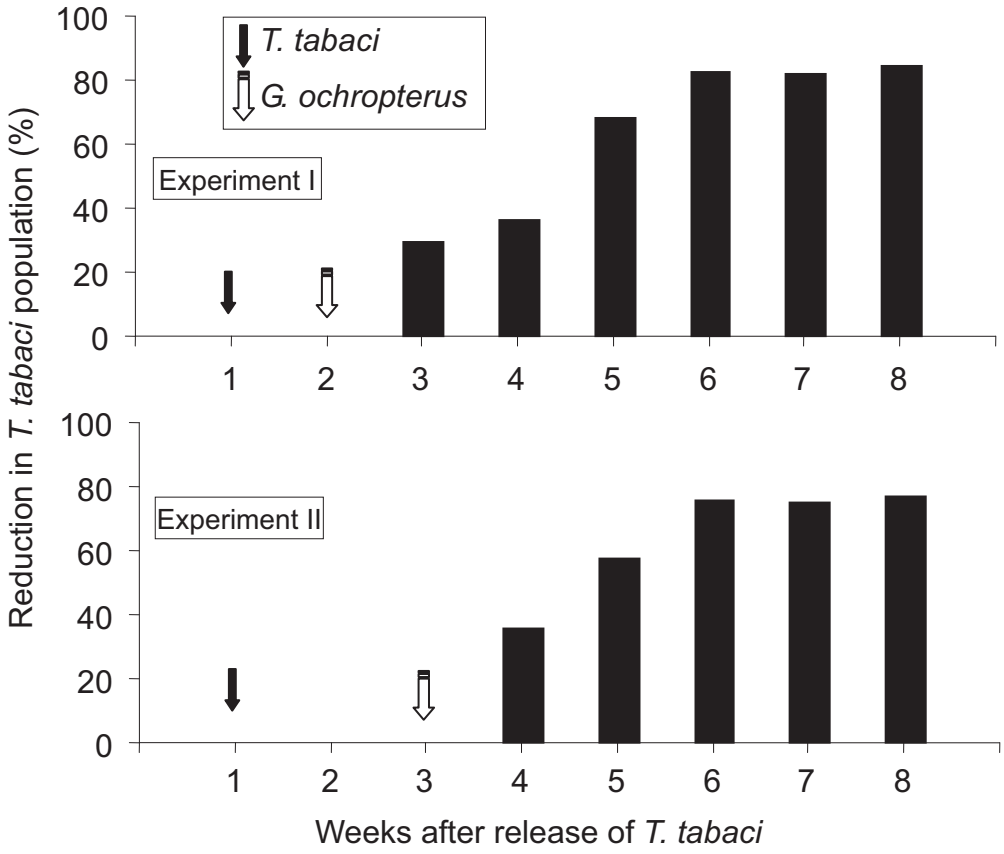

Fig. 64: Percentage reduction in *Thrips tabaci* population on sweet pepper plants compared with the control experiment after one week (experiment I) and two weeks (experiment II) of *Geocoris ochropterus* release in greenhouse

3.2.3 Efficiency of *Geocoris ochropterus* against *Gynaikothrips ficorum*

In experiment I, the mean total number of *G. ficorum* from eggs to adults was 30.7 thrips/plant in the 1st week after infestation (Fig. 65). The population of *G. ficroum* reached a maximum of 108.7 thrips/plant in the 3th week. Afterwards, it decreased continuously till it reached a mean of 26.7 thrips/plant in the last experimental week.

In experiment II, the mean total number of the thrips was 41.0 thrips/plant in the 1st week after infestation, and its maximum was 125.7 thrips/plant in the 3th week. After that, the mean total of *G. ficorum* of different instars continued to decrease till it reached 48.0 thrips/plant in last experimental week.

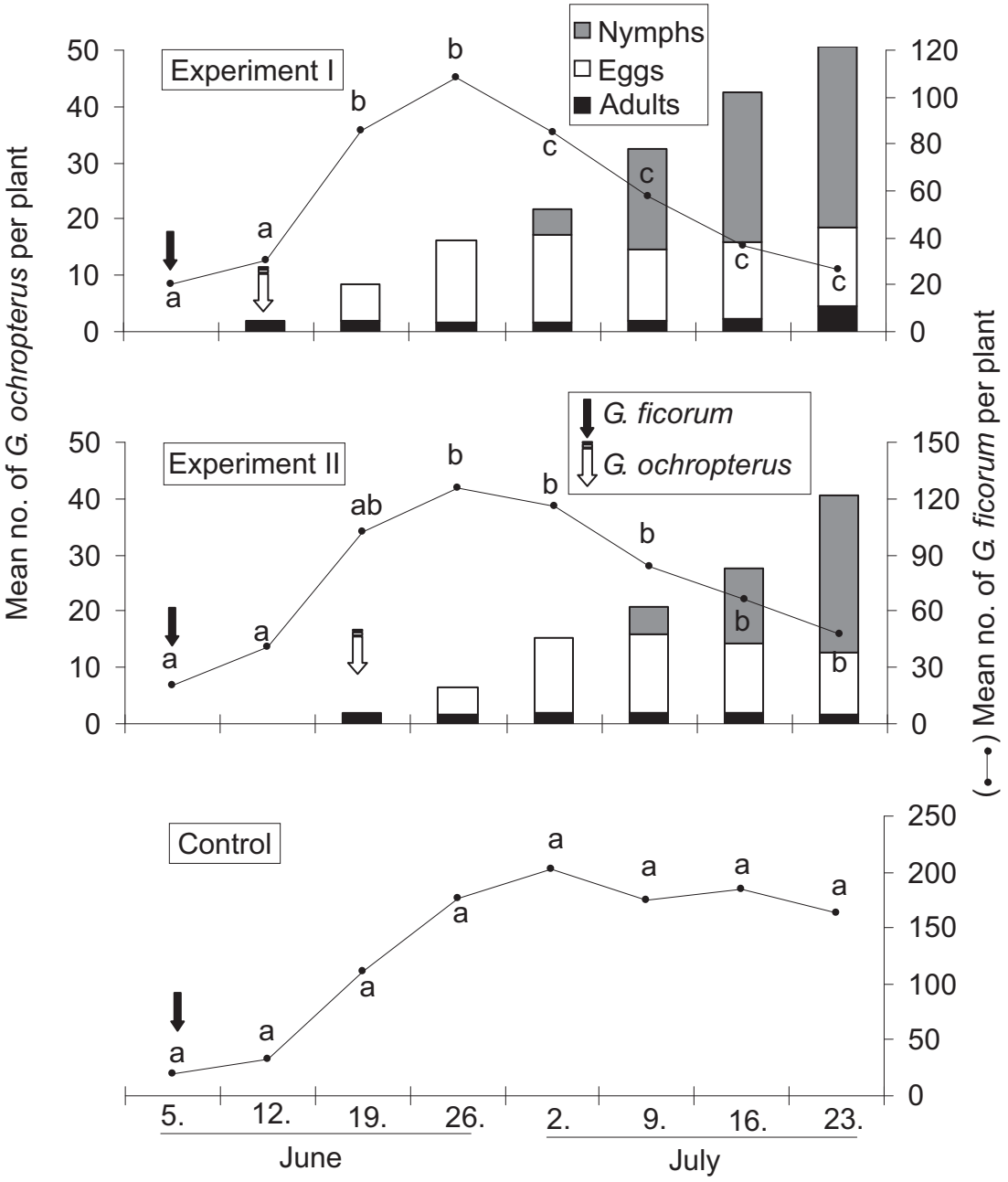

Fig. 65: Mean numbers of *Geocoris ochropterus* (adult, nymph and egg stages) and *Gynaikothrips ficorum* (all stages) per *Ficus microcarpa* tree one week (experiment I) and two weeks (experiment II) after releasing as well as the control experiment in greenhouse. [Different letters indicate significant differences in the mean numbers of *G.ficorum* within the same week in the three different experiments at $p \leq 5\%$ (one-factor ANOVA)]

However in the experiment III, where no predator were released, the mean total number of the thrips from different life stages was 32.3 thrips/ plant in the 1st week after infestation, and it reached a maximum of 202.3 thrips/predator in the 4th week, after that it continuously declined

till it reached 163.7 thrips/plant. The mean number of *G. ficorum* was significantly higher in the experiment III than in the other both experiments one week of predator releasing. The mean number of thrips in experiment II was significantly higher than that in experiment I after the 4th week of *G. ficorum* infestation.

The total number of *G. ochropterus* in experiment I was a mean of 1.7 adults, 14.7 eggs per plant in 3th week after infestation of the thrips. It increased to 4.7 adults, 14.0 eggs and 32.0 nymphs per plant in last experimental week. In experiment II, the number of *G. ochropterus* was 1.7 adults, 4.7 eggs during the 3th week per plant. It increased to 1.7 adults, 11.0 eggs and 28.0 nymphs per plant in last experimental week.

Figure 66 indicates the reduction of *G. ficorum* population caused by *G. ochropterus* release.

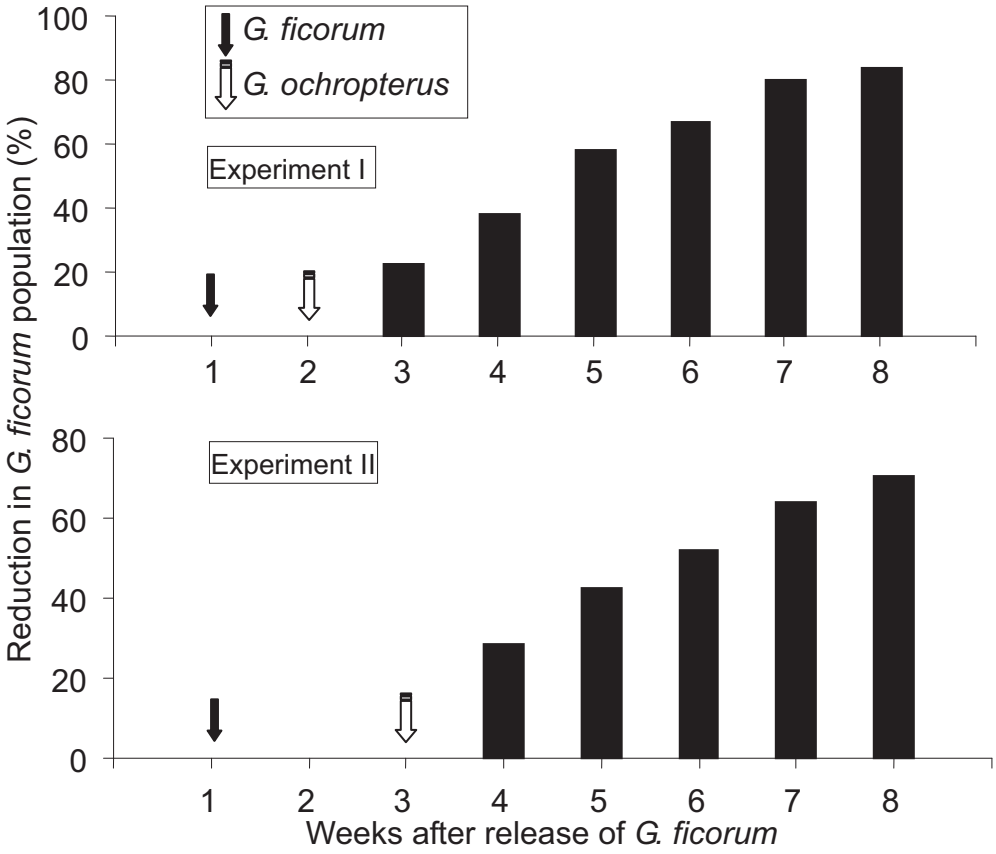

Fig. 66: Percentage reduction in *Gynaikothrips ficorum* population on *Ficus microcarpa* trees compared with the control experiment after one week (experiment I) and two weeks (experiment II) of *Geocoris ochropterus* release in greenhouse

In experiment I, the percentage reduction of *G. ficorum* population (Fig. 66) was 22.6% one week after *G. ochropterus* release. The reduction of thrips was 58.0% in the 3rd week and 67.2% in the 4th week. Maximum reduction of 83.7% in *G. ficorum* population was achieved in experiment I in the last experimental week. In the case of experiment II, the reduction of thrips was 28.5% in the 1st week after predator release. It was 52.1.8% in the 3rd week. The reduction in the thrips population in cabin II reached its maximum in the last experimental week, where it was 70.7%.

4 DISCUSSION

In order to enrich the predators for biological control of *F. occidentalis*, *T. tabaci* and *G. ficorum*, the current study was comprehensively conducted on the four predatory bug species: *G. ochropterus*, *M. moraguesi*, *O. similis* and *S. subula*. Firstly, the biology and prey consumption of the four predatory bug species were experimented at temperature 25±1°C. After that, *G. ochropterus*, which displayed high prey consumption, fecundity and long longevity, was selected for further studies on biology and prey consumption at 18 and 30±1°C temperatures, as well as the prey consumption in changing prey offer. The effect of different extreme temperatures on *G. ochropterus* was also observed. Moreover, experiments were conducted to investigate the preference of *G. ochropterus* for prey ages and species, as well as the effect of different nutritions. The cannibalism of *G. ochropterus* and the intraguild predation between *G. ochropterus* and *O. similis* were also determined. Finally, greenhouse experiments were made to confirm the efficiency of *G. ochropterus* for the biological control of the pest thrips.

Biology and prey consumption of the four predatory bug species

The present results showed that *G. ochropterus*, *M. moraguesi* and *O. similis* were successful to complete life cycles with the 3 thrips species as prey at temperature 25±1°C. However, *S. subula* could only develop from egg to the 4th instar. KAPADIA & PURI (1991) reported that the embryonic developmental periods of *G. ochropterus* were 11-18 days with *B. tabaci* as prey at 23.7±1.9°C, similar to that with the three thrips species as prey in current results. The period of whole nymphal development was 26-33 days with *B. tabaci* as prey at 23.7±1.9°C (KAPADIA & PURI 1991). It was not only shorter than that with the three thrips species as prey at 25±1°C in current results, but also than that in the research conducted by MUKHOPADHYAY & SANNIGRAHI (1993), who revealed that *G. ochropterus* nymphs completed the entire development in 27-36 days with ant pupae of *Oecophylla smaragdina* Fabr. as prey at 27±1°C. These differences may be due to the prey ages and species as well as the rearing climatic condition. The periods of embryonic and nymphal development of similar species *Geocoris pallidipennis* (COSTA) were 7-8 and 27 days with mixture of aphid *Brevicoryne brassicae* (LINNAEUS) and pink boll warm

Helicoverpa armigera (HUBNER) as prey at 27±1°C (AI et al. 1989). This indicated that some *Geocorsi* species may take quite long time to complete the immature development. Embryonic and nymphal developmental periods of *O. similis* were 5.1-5.6 and 14.0-21.8 days with aphid species as prey at 25±1°C, respectively (SENGONCA et al. 2008). In another *Orius* species, *Orius albidipennis* (Reuter), the period of the embryonic development was 3-4 days (CHYZIK et al. 1995) and the period of nymphal developmental was 17.6 days period (FRITSCHE & TAMO 2000). In current research, *O. similis* completed embryonic and nymphal development with different thrips species as prey in average 3.1-3.6 days and 11.9-13.9 days, respectively. The prior researches mentioned above also showed that immature periods of the *Geocoris* species were longer than those of the *Orius* species. This trend was also found in the current results. No similar researches on *M. moragues* and *S. subulai* were reported.

The mortality of *G. ochropterus* from the 1st instar to the adult emergence was 17.6% with *O. smaragdina* pupae as prey at 27±1°C (MUKHOPADHYAY & SANNIGRAHI 1993). It was similar to that with *G. ficorum* as prey, but higher than that with *F. occidentalis* and *T. tabaci* as prey at 25±1°C in current results. The mortality differences may be caused by the different prey species. During the whole nymphal development of *O. similis*, SENGONCA et al. (2008) revealed that the mean total mortality was ranged from 20.0 to 34.4%, depending on the different aphid species as prey. SANCHEZ and LACASA (2002) reported the survivorship of *Orius laevigatus* (Fieber) and *O. albidipennis* with *F. occidentalis* as prey at 25±1°C, where the total mortality from egg to adult emergence were about 36 and 14% for the both *Orius* species, respectively. This shows that the mean mortality of *O. similis* in the current research is within the range reported in literatures. The reports on the mortality of *M. moraguesi* and *S. subula* are not available.

Adult females and males of *G. ochropterus* lived for 28-34 days and 12-19 days with *B. tabaci* as prey at 23.7±1.9°C, respectively (KAPADIA & PURI 1991). With *O. smaragdina* pupae as prey at 27±1°C, the longevity of *G. ochropterus* was 66-89 days for females with constant male company, 30-92 days for females mated fortnightly, and 67-124 days for virgin females (MUKHOPADHYAY & SANNIGRAHI 1993). The longevity of *G. ochropterus* in current researches at 25±1°C was considerably longer than that reported by KAPADIA & PURI (1991), but similar to that revealed by

MUKHOPADHYAY & SANNIGRAHI (1993). The longevity of *O. similis* varied from 16.4 to 37.9 days (mated ♀♀) and from 27.2 to 34.0 days (♂♂), depending on aphid species as prey (SENGONCA et al. 2008). This was similar to the longevity of *O. similis* in current researches. The reports mentioned above indicated that the longevity of *G. ochropterus* was possible to be longer than that of *O. similis*. This trend was found in the current research too. In present study, the differences of longevity between females and males of *G. ochropterus* varied according to prey species. This phenomenon was also shown in the study conducted by CHYZIK et al. (1995), where the longevity of *O. albidipennis* females was similar to that of the males with eggs of *Ephestia cautella* (WALKER) as prey, but it was shorter than that of the males with *T. tabaci* or *T. urticae* as prey. There was no available knowledge about the longevity of *M. moraguesi* and *S. subula* in the literature.

The fecundity of *G. ochropterus* was a mean of 277 eggs/♀ with *O. smaragdina* pupae as prey at 27±1°C (MUKHOPADHYAY & SANNIGRAHI 1993). It is higher than the fecundity of *G. ochropterus* in current study. The differences may be caused by prey species. *G. pallidipennis* was reported to lay 97-130 eggs/♀ with mixture of aphid *B. brassicae* and moth *H. armigera* as prey at room temperature 26.1-33.3°C (Sun 1993). Its fecundity was similar to that of *G. ochropterus* with *F. occidentalis* and *T. tabaci* as prey, but lower than that of *G. ochropterus* with *G. ficorum*. In reported researches on *O. similis*, WEI et al. (1984) revealed that the fecundity was 17-101 eggs/♀ by feeding on *Thrips flavus* SCHRANK. SENGONCA et al. (2008) reported that the fecundity of *O. similis* varied from 58 to 160 eggs/♀ according to aphid species as prey. In present study, *O. similis* produced from 60.0 eggs/♀ with *T. tabaci* to 104.6 eggs/♀ with *F. occidentalis* as prey.

In terms of prey consumption at temperature 25±1°C, *G. ochropterus* was superior predator over *M. moraguesi* and *O. similis* within same thrips species as prey. *S. subula* Nymphs were not successful to live on the 3 thrips species after they grew into N_5 instar, and all of them died before adult emergence. In the literatures, where whitefly *B. tabaci* was used as prey, daily prey consumption of N_3 and female adult *G. ochropterus* was averaged 7.5 and 8.1 whitefly nymphs (2^{nd}-3^{rd} instars), respectively (KAPADIA and PURI 1991). In contrast, N_3 and female adult of *O.*

laevigatus daily killed only 1.7 and 8 whitefly nymphs, respectively; N_3 and female adult of *O. majusculus* daily consumed 4.7 and 10.7 whitefly nymphs, respectively (ARNÓ and RIUDAVETS 2008). Female adult *Geocoris punctipes* SAY was reported to daily kill 35.2 female adult whiteflies (GOHEN & BYRNE 1992). Comparatively, female adult *O. laevigatus* and *Orius majusculus* (REUTER) daily consumed 7.7 and 10.7 female adult whiteflies, respectively (ARNÓ and RIUDAVETS 2008). This is in agreement with the current results.

Biology and prey consumption of *Geocoris ochropterus* at different temperatures

High fecundity and consumption rate per day were important characteristics for a predator species to be used in pest biological control (BLAESER et al. 2004). *G. ochropterus* was not only successful to complete life circle with *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey, but also showed significantly longer longevity, higher fecundity and daily prey consumption than the other two successful species: *M. moraguesi* and *O. similis*. Therefore, it was selected for further research.

G. ochropterus was able to complete life cycle with the 3 thrips species as prey at temperature 18 and 30°C. Mean periods of embryonic and total nymphal development were significantly longer at 18°C than at 30°C. It is a common phenomenon that insects can grow faster with increasing temperature within a certain range. DUNBAR and BACON (1972) also reported that *Geocoris atricolor* MONTANDON, *Geocoris pallens* STÅL and *G. punctipes* developed faster with increasing temperature under 37.8°C. In the present research, the mortality of *G. ochropterus* was significantly higher at 18°C than at 30°C. This trend was also found in *O. albidipennis* (COCUZZA et al. 1997), *Orius strigicollis* (POPPIUS) (KIM et al. 1999), *O. similis* (SENGONCA et al. 2008) and Ladybird *Serangium parcesetosum* SICARD (SENGONCA et al. 2004). All these predatory species successfully completed immature development with significantly higher mortality and longer duration at 15 or 18°C than at 30 or 35°C as reported in the literatures.

Mean longevities of adult *G. ochropterus* in both sexes were significantly longer at 18°C than at 30°C. The inverse relation between longevity and temperature has been found in other predatory bug species. AHMADI et al. (2007) reported that the longevity of *O. similis* was significantly

longer at 18°C than at 30°C. Adult females of *O. strigicollis* showed longer longevity at 23°C than at 29°C (KAKIMOTO et al. 2005). In the same trend, ladybird *S. parcesetosum* lived a longer longevity at 18 °C than at 30°C (SENGONCA et al. 2004).

In the current study, the adult females of *G. ochropterus* displayed a significantly higher fecundity at 30°C than at 18°C. Such trend was followed by some *Geocoris* species. DUNBAR and BACON (1972) reported that *G. atricolor*, *G. pallens* and *G. punctipes* had maximal oviposition at a certain temperature over 30°C.

G. ochropterus significantly consumed more thrips at the higher temperature than at the lower temperature. Similar effect of temperature on the prey consumption was also recorded in the predatory bug *G. punctipes*. CROCKER et al. (1975) reported that *G. punctipes* daily consumed greater numbers of the soybean looper eggs, *Pseudoplusia includens* (WALKER), at each higher experimental temperature (20, 25, 30 and 35 °C), excepting that the female adults daily consumed fewer prey at 35 than at 30 °C. COHEN (1984) also revealed that *G. punctipes* increased its oxygen consumption rate with increasing temperatures (24, 30 and 35 °C).

Prey consumption by *Geocoris ochropterus* in changing prey offer

In agro-ecosystem, the prey's population available for a natural enemy will be never constant and it fluctuates in relation to many factors. In order to be considered as a successful natural enemy, a predator is expected to be capable to adapt itself and react efficiently to such fluctuations in prey availability. In the present experiments, *G. ochropterus* exhibited adaptability to the fluctuation in prey availability. Its daily prey consumption increased with higher prey density until the number of available prey was over a level. For example, when 5, 10, 20 and 50 L_2 larvae of *F. occidentalis* or *T. tabaci* were daily offered as prey, the adult females of *G. ochropterus* consumed significantly more preys in the higher prey density than in the lower ones. However, when the prey species was replaced with *G. ficorum*, the predators presented no significant difference of prey consumption among the three high prey densities where 10, 20 and 50 L_2 thrips were daily offered as prey. The reason is that L_2 *G. ficorum* is bigger in size than L_2 *F. occidentalis* and *T. tabaci*, and the number of 10 L_2 *G. ochropterus* per days is enough for an

adult female of *G. ochropterus*. At lower prey density, the predator could kill most of the offered prey individuals. Although the response of *G. ochropterus* to changing prey density was not previously documented, its related species, *G. punctipes*, was reported to kill more eggs of cotton bollworm (Helicoverpa zea) in relation to the prey density (PARAJULEE, et al 2006). The present results also agree with ALVARADO et al. (1997), who revealed that the prey consumption of *D. tamaninii* increased until satiation as more prey individuals were offered. The response of ladybird *S. parcesetosum* to fluctuating prey density, which was reported by SENGONCA et al. (2005), was in the same pattern as that of *G. ochropterus* too.

Effect of extreme temperatures on *Geocoris ochropterus*

The adaptability of a natural enemy to extreme high and low temperatures is an essential prerequisite for its successful utilization in a biological control program. The current results demonstrated that extremely high constant and changing temperatures were showed no adverse effect on the immature development of *G. ochropterus*. The predatory bug developed quickly with total mortality of 20-35% from N_1 to adult emergence. This phenomenon was also observed in *G. atricolor*, *G. pallens* and *G. punctipes*, which could complete development at 35^{o}C with shorter period of time than at lower temperature (DUNBAR and BACON 1972). The current results showed that the mean daily prey consumption of *G. ochropterus* was higher at the extremely high temperatures than at 18, 25 and 30^{o}C. This is consistent with the trend found by CROCKER et al. (1975), who revealed that nymphs of *G. punctipes* consumed greater numbers of prey daily at each higher experimental temperature: 20, 25, 30 and 35^{o}C.

Under extremely low temperatures 3 and 6^{o}C, *G. ochropterus* kept alive for a considerable period of time. Many insect species, in the orders like Coleoptera, diptera, Heteroptera, Hymenoptera and Neuroptera as well as Acarina, show high tolerance to cold temperature (KOK & MCAVOY 1983, GILKESON 1992, MOREWOOD 1992, RUDOLF et al. 1993, WHITAKER-DEERBERG et al. 1994). RUDOLF et al. (1993) reported that *O. laevigatus* adults survived for 50 days under the changing temperature 13/3^{o}C. Another predatory bug *Podisus maculiventris* (SAY) adults survived for 2 months at 9^{o}C (DE CLERCQ and DEGHEELE 1993). The species in order Coleoptera usually show strong tolerance to extremely low temperature. Adult *Hippodamina convergens*

GUÉRIN-MÉNEVILLE survived for 4-6 months at 3°C (DAVIS and KIRKLAND 1982) and Adults of Ladybird *Leis axyridis* PALLAS could live for 100-140 days at 5°C (DENG 1982). The tolerance to cold temperature differed much between the different species in same order, even in same family. For example, the larvae of parasitoid *Telenomus theophile* WU & CHEN could survived for more than 2 months at 4°C (LIANG and HU 1989), while larvae of *Telenomus remus* NIXON lived for 6-16 days at 10°C (MCDONALD and KOK 1990). *G. ochropterus* in present research also showed stronger tolerance to cold temperature than *O. laevigatus* (RUDOLF et al.1993) and *P. maculiventris* (DE CLERCQ and days EGHEELE 1993). *G. ochropterus* presented higher survival rates than the eggs and N_3 nymphs at the extremely low temperature in the current research. This is in consistent with the trend in the predatory bug *P. maculiventris*, adults of which could lived for 2 months at 9°C, but its eggs could only endure for 6 days at that temperature (DE CLERCQ & days EGHEELE 1993).

Prey preference by *Geocoris ochropterus*

To valuate the suitability of a predator for biological control of one or some pest species, it is necessary to investigate its preference for a certain pest stage or even the pest species. This is true especially when it is taken into account that the predator is polyphagous and in the agro-ecosystem, there are naturally several pest species, which might serve as potential prey for the predator. Taking into consideration the polyphagous nature of *G. ochropterus*, experiments were set up to study its prey preference for prey stage and species.

G. ochropterus, tested at life stages of N_2, N_4 and 7-day-old female adult, was able to prey on each of L_1, L_2 and female adults of the 3 pest thrips. However, at all of the tested life stages, the predator showed the preference for the adult over the larvae when *F. occidentalis* or *T. tabaci* was offered as prey. The prey preference was in another trend when *G. ficorum* was the prey species, where N_2 *G. ochropterus* preferred larval thrips over adult ones, while N_4 *G. ochropterus* showed no clear preference between the thrips stages, female adult of *G. ochropterus* preferred L_2 and adult over the L_1 thrips. *G. punctipes* was also reported to showed preference for the adult whitefly over the immature ones when the adult predator was exposed to a choice of different

prey stages (HAGLER et al. 2004). On other predatory bugs against thrips, NAGAI et al. (2000) reported that preference of *Orius sauteri* (POPPIUS) between adults and larvae of *Thrips palmi* KARNY changed with the life stages of the predator develop. This is similar to the current results with *G. ficorum* as prey.

Among different vegetable pest species offered as prey, *G. ochropterus* preferred *T. tabaci* and *F. occidentalis*. In literatures, *G. ochropterus* was reported not only a predator of some thrips (KUMAR and ANANTHAKRISHNAN 1985) but also a predator of whitefly *B. tabaci* (KAPADIA et al. 1991). In present research, the predatory bug predated the two prey species too. KUMAR and ANANTHAKRISHNAN (1985) reported that *G. ochropterus* preferred thrips > mites > aphids > tingids > whitefly. This agreed with the current results. HAGLER et al. (2004) reported that another related predatory bug, *G. punctipes*, also showed a significant preference when it was expose to a choice of *Lygus Hesperus* KNIGHT, *Aphis nerii* BOYER de FONSCOLOMBE, *Heliothis zea* (BODDIE), *Heliothis virescens* (FABRICIUS) and *Spodoptera exigua* (Hübner) as preys. Another research indicated that *G. punctipes* preferred *T. urticae* to *A. gossipii* (SILVIA et al. 2004). In present research, *G. ochropterus* also preferred *T. urticae* to *A. gossipii* as well as *B. tabaci*, except that the predator was in N_2 stage where it showed no preference for prey species.

Effect of different nutrition on *Geocoris ochropterus*

Knowledge of the effect of different nutrition on *G. ochropterus* is helpful to estimate the survival of the predators after it is released. Therefore, experiments were set up to determine how long the N_4 and adult *G. ochropterus* would develop or survive with different nutrition under laboratory condition. The results demonstrated that N_4 and adults of *G. ochropterus* lived for significantly different periods of time between some prey species. This is due to the different developmental period and longevity caused by different prey species. It is possible that prey species and life stages can affect the developmental period and longevity of a predator. TORRES et al. (2004) reported that nymphal development of *Geocoris floridanus* BLATCHLEY was longer by feeding on beet armyworm larvae, *S. exigua*, than by feeding on eggs of *Helicoverpa zea* (BODDIE). DUNBAR et al (1972) studied the feeding, development and reproduction of *G.*

punctipes on 8 diets, revealing some diets were suitable and some are not. NARANJO and STIMAC (1985), who studied on *G. punctipes*, revealed that supplementing a prey diet with plant food resulted in shorter developmental time for certain instars of *G. punctipes* as well as greater nymphal survival of the predator. This phenomenon was also observed in present research. Without prey insects offered as food, N_4 and Adult *G. ochropterus* could live for considerable long time by feeding on 10% honey emulsion. AHMADI et al. (2007) also reported that adult *O. similis* was able to survive significantly longer on 10% honey emulsion than on pollen and only broad been leaf.

Cannibalism and intraguild predation by *Geocoris ochropterus*

Cannibalism of *G. ochropterus* and its intraguild predation with *O. similis* were recorded in the current research. In literatures, such phenomenon was also found in some *Geocoris* species. ROSENHEIM (2005) reported that *Orius tristicolor* (WHITE), in the manipulative field experiments, was subject to strong predation by other predator community, and in particular by *Geocoris* spp. GUILLEBEAU and ALL (1989) reported the intraguild predation between *Geocoris* spp. and the striped lynx spider, *Oxyopes salticus* HENTZ (Araneae: Oxyopidae). The present results showed that the cannibalism and intraguild could significantly decline when sufficient prey was available. Such trend was followed by many generalist predatory species. GILLESPIE and QUIRING (1992) reported that *O. tristicolor* reduced intraguild predation upon the phytoseiid mite *Amblyseius cucumeris* (OUDEMANS) with increasing densities of their common prey *F. occidentalis*. A great reduction was also recorded in intraguild redation between larvae of *Chrysoperla carnea* (STEPHENS) and *Chrysoperla septempunctata* LINNAEUS when aphids were added (SENGONCA and FRINGS 1985). These reports are consistent with the current results. It was also revealed that the larger-size species are likely to kill the smaller species (SENGONCA and FRINGS 1985, GILLESPIE and QUIRING 1992). This trend was found in the current research. Female adult *G. ochropterus* is far larger than the N_3 and female adult *O. similis*. It was always observed to be the predator against the latter. However, the activeness also plays an important role in the intraguild predation. N_3 of *G. ochropterus* is in a similar size of female adult *O. similis*. They can attack each other with a little advantage for female *O. similis*. Eggs of *G. ochropterus*, which are inactive and little in size, are always the victim in cannibalism and intraguild predation.

Greenhouse experiments

Under greenhouse condition, *G. ochropterus* was successful to feed, reproduce and establish its population in pepper plants with *F. occidentalis* or *T. tabaci*, banyan trees with *G. ficorum* as pest thrips. Releasing a pair of *G. ochropterus* adults per plant was able to cause up to 92.1, 85.7, and 83.7% reductions in the populations of *F. occidentalis*, *T. tabaci* and *G. ficorum*, respectively. KUMAR and ANANTHAKRISHNAN (1985) reported that *G. ochropterus* was abundant on groundnuts and on the weed *Achyranthes aspera* LINN. in India, where it is a predator on the thrips *Ayyaria chaetophora* KARNY, *Caliothrips indicus* (BAGNALL) and *Scirtothrips days orsalis* HOOD. It was still reported to feed on *B. tabaci* immature in cotton field under Parbhani conditions of Maharashtra State (KAPADIA and PURI 1991). These reports indicates that *G. ochropterus* is possible to build its population in field and act as a efficient predator for some pest insect, and partially support the present results of the greenhouse experiments.

In present greenhouse experiments, the efficiency of *G. ochropterus* in reducing the thrips population was higher when the predator was released 1 week rather than 2 weeks after the pest thrips infestation. This shows that an early release of *G. ochropterus*, when the thrips population is still low, would be more effective in its control. This trend was also followed by other predators. For example, when *Macrolophus caliginosus* WAGNER was introduced to control whitefly on tomato in 24 Dutch greenhouses at different release timings and rates, the most effective introduction was the one which was made early in the season with a minimum release rate of 1 predator/m^2 (SAMPSON and KING 1996).

Conclusion

With pest thrips *F. occidentalis*, *T. tabaci* and *G. ficorum* as prey at temperature 25±1^{o}C, predatory species *G. ochropterus*, *M. moraguesi* and *O. similis* successfully completed their life cycles, while *S. subula* failed. In terms of the daily prey consumption, fecundity and longevity, *G. ochropterus* was the superior predator over the other 3 predatory species. In further study, *G. ochropterus* exhibited considerable adaptability to a wide range of extremely low, moderate and

extremely high temperatures. It could also smoothly adapt to changing prey availability. In addition, it could polyphagously feed on different arthropod species with clear preference for thrips. Moreover, *G. ochropterus* tended to avoid cannibalism and intraguild predation behaviours with sufficient prey species. Under greenhouse condition, *G. ochropterus* was successful to feed, reproduce and establish its population as well as cause a high reduction in the 3 pest thrips species. However, there are still some points for further investigation, for example, impact of selective insecticides on its biology and predation efficacy, persistence of its population under field condition, the interaction between *G. ochropterus* and other natural enemies under field condition and the feasible method for mass rearing of the predator.

SUMMARY

The four predatory bug species, *Geocoris ochropterus* FABR. (Het., Lygaeidae), *Montandoniola moraguesi* (PUTON) (Het., Anthocoridae), *Orius similis* ZHENG (Het., Anthocoridae) and *Scipinia subula* HSIAO et REN (Het., Reduviidae) were reported abundant in fields of some regions and able to feed on pest thrips. It is valuable to comprehensively investigate their potential use for biological control of pest thrips. However, such knowledge of the four predatory bug species is very lacking in the literature. Therefore, the current research aimed to study these four predatory bug species as candidate bio-agents for biological control of the three important pest thrips: *Frankliniella occidentalis* (PERGANDE) (Thy., Thripidae), *Thrips tabaci* LINDEMAN (Thy., Thripidae) and *Gynaikothrips ficorum* (MARCHAL) (Thy., Phlaeothripidae).

The results showed that all the tested predators, excepting *S. subula*, were able to complete life cycles with the 3 thrips species as prey at temperature 25±1°C. Among the 3 successful predatory species, the embryonic developmental period varied according to different parental prey species. The period showed the longest in *G. ochropterus* eggs with average 15.9-17.2 days, and the shortest in *O. similis* eggs with average 3.1-3.6 days. The nymphal developmental period from N_1 to adult emergence was the longest in *G. ochroperus* with average 34.9-37.3 days, and was the shortest in *O. similis* with average 11.9-13.7 days. During the development, the mortality of eggs was very low for all tested predatory speices. The mortality of *G. ochroperus*, *M. moraguesi* and *O. similis* from N_1 to adult emergence varied according different prey species with a range of 15-35%. Sex ratio, or in another word, the percentage portion of females showed no significant difference among the 3 successful predatory species, and ranged from 47.9% (♀♀) in *O. similis* with *T. tabaci* to 58.7% (♀♀) in *G. ochropterus* with *F. occidentalis* as prey.

At temperature 25±1°C, the longevity of *G. ochropterus* with each thrips species as prey was average 63.3-75.0 ♀♀, 50.2-57.1 ♂♂ days. It was significantly longer than that of the other predatory species. The significant shortest longevity was recorded in *S. subula*, where it varied from 10.4-12.7 ♀♀ and 11.0-13.1 ♂♂ days. Over the whole longevity, the total fecundity of *G. ochropterus* varied according to prey species with 112.1-154.4 eggs/♀. It was 34.6-99.8 eggs/♀ for *M. moraguesi* and 60.0-104.6 eggs/♀ for *O. similis*, and 2.0-15.7 eggs/♀ for *S. subula*.

At 25±1°C, the daily prey consumption by *G. ochropterus* throughout the whole nyphal development was averaged 6.8 (*F. occidentalis*), 9.3 (*T. tabaci*) and 2.9 (*G. ficorum*) thrips. It was significantly higher than that of *M. moraguesi* (2.3-4.9 thrips) and *O. similis* (1.8-4.8 thrips) within same prey species. Mean total prey consumption by *G. ochropterus* throughout the nymphal development was 270.2 (*F. occidentalis*), 329.6 (*T. tabaci*) and 102.9 (*G. ficorum*) thrips. It was also significantly higher than that of *M. moraguesi* and *O. similis* within same prey species. *S. subula* was not able to feed on the 3 thrips species after it reach N_5 stage. During the first 15 days after adult emergence, *G. ochropterus* consumed a total of average 128.2 (*G. ficorum*)-243.5 (*T. tabaci*) thrips/♀ and 116.1 (*G. ficorum*)-205.2 (*F. occidentalis*) thrips/♂. The total prey consumption of *G. ochropterus* was significantly higher than that of the other 3 predatory bug species within same predator sex and prey species.

Because of its good property in biological control of thrips species, *G. ochropterus* was selected for further research. At temperature 18±1°C, the mean periods of embryonic and total nymphal development changed according to thrips species prey with a value of 41.5-42.7 days and 93.7-103.0 days, respectively. At temperature 30±1°C, the periods became significantly shorter (11.1-11.6 days for embryonic development and 25.9-31.4 days for total nymphal development). The mortality during immature development was significantly higher at 18 °C than at 30°C. The longevity of *G. ochropterus* adults was average 59.4-81.8 ♀♀ and average 58.8-76.4 ♂♂ days at 18°C, significantly longer than at 30°C [29.7-39.0 ♀♀ days, 27.4-35.3 ♂♂ days]. The mean total fecundity with different thrips species as prey ranged 12.1-52.6 eggs/♀ at 18°C, significantly lower with longer pre-oviposition period than at 30°C (67.2-128.1 eggs/♀).

G. ochropterus significantly consumed more thrips as temperature increased. It also killed significantly more L_1 than L_2 thrips within same temperature. Throughout the whole nymphal days evelopment, *G. ochropterus* nymphs consumed the 3 thrips species with an average total number of 196.7-245.8 L_1 or 120.6-174.3 L_2 thrips at 18°C, and 339.1-804.8 L_1 or 103.6-232.2 L_2 thrips at 30°C. The total prey consumption by adult females of *G. ochropterus*, over whole

longevity, was 427.2-727.7 L_1 or 271.6-374.7 L_2 thrips at 18°C, and 595.4-2059.8 L_1 or 388.0-1444.3 L_2 thrips at 30°C. For adult males of *G. ochropterus*, the mean total prey consumption was 368.8-550.2 L_1 or 227.2-310.8 L_2 thrips at 18°C, and 595.4-1848.2 L_1 or 388.0-1178.7 L_2 thrips at 30°C.

G. ochropterus could adapt to fluctuating prey density. Its daily prey consumption increased with higher prey density until the number of available prey was over a level. At lower prey density, the predator could kill most of the offered prey individuals. Moreover, extremely high constant (35±1°C) and changing temperatures (35/25±1°C) revealed no adverse effect on the development and prey consumption of *G. ochropterus* during the immature stages. The eggs hatched in 9.7 days at 35 °C, significantly slower than at 35/25°C (8.3 days). With different thrips species as prey, *G. ochropterus* completed the total nymphal development in 17.6-20.1 days at the two temperatures. The mean daily prey consumption was significantly higher at 35°C than at 35/25°C within same thrips species. Under extremely low temperatures 3 and 6±1°C, *G. ochropterus* kept alive for a considerable period of time. The predator showed higher tolerance to temperature 6°C than to 3°C. The adult predator presented higher survival rates than the eggs and N_3 nymphs, when they were kept under the same extremely low temperature for same period of time.

When *F. occidentalis* or *T. tabaci* was offered as prey, *G. ochropterus* showed significant prey preference for adult thrips over the larval ones. With *G. ficorum* as prey, the prey-age preference of *G. ochropterus* changed according to the predatory stages. Among different vegetable pest species offered as prey, *G. ochropterus* preferred *T. tabaci* and *F. occidentalis*. Without prey offered as food, N_4 and adults of *G. ochropterus* could live for considerable days by feeding on 10% honey emulsion. *G. ochropterus* could commit cannibalism and intraguild predation with *O. similis*. Such phenomenon could significantly reduce when sufficient prey was available.

Under greenhouse conditions, *G. ochropterus* was successful to feed, reproduce and establish its population in the infestation of the 3 pest thrips species. Releasing a pair of *G. ochropterus* adults per plant leaded to 92.1, 85.7, and 83.7% reductions in the populations of *F. occidentalis*, *T. tabaci* and *G. ficorum*, respectively.

REFERENCES

AHMADI, K., SENGONCA, C. and BLAESER P., 2007. Effect of two different temperatures on the biology of predatory flower bug *Orius similis* ZHENG (Heteroptera: Anthocoridae) with two different aphid species as prey. Türk. Entomol. Derg. 31(4), 253-268.

AI, S. Z. and ZHU, Z. X., 1989. Elementary study on biology of *Geocoris pallidipennis* (Heteroptera : Lygaeidae). Nat. Enem. Insects 11(1), 36-38.

ALVARADO, P., BATTA, O. and ALOMAR, O., 1997. Efficiency of four Heteroptera as predators of *Aphis gossypii* and *Macrosiphum euphorbiae* (Hom., Aphididae). Entomophaga 42, 215-226.

ANANTHAKRISHNAN, T. N., 1993. Bionomics of thrips. Annu. Rev. Entomol 38, 71-92.

ANONYMOUS, 2002. SAS/STAT user's Guide. Version 9.1. SAS Institute. Cary, NC.

ARNÓ, J., ROIG, J. and RIUDAVETS, J., 2008. Evaluation of *Orius majusculus* and *O. laevigatus* as predators of *Bemisa tabaci* and estimation of their prey preference. Biol. Control 44, 1-6.

BLAESER, P., SENGONCA, C. and ZEGULA, T., 2004. The potential use of different predatory bug species in the biological control of *Flankliniella occidentalis* (PERGANDE) (Thysanoptera: Thripidae). J. Pest Science 77, 211-219.

BRAMAN, S. K. and BESHEAR R. J., 1994. Seasonality of predaceous plant bugs (Heteroptera: Miridae) and phytophagous thrips (Thyanoptera: Thripidae) as influenced by host plant phenology of native azaleas (Ericales: Ericaceae). Environ. Entomol. 23, 712-718.

CASTAÑÉ, C., ALOMAR, O. and RIUDAVETS, J., 1996. Management of western flower thrips on cucumber with *Dicyphus tamaninii* (Heteroptera: Miridae). Biol. Control 7(1), 114-120.

CHYZIK, R., KLEIN, M. & BEN-DOV Y., 1995. Reproduction and survival of the predatory bug *Orius albidipennis* on various arthropod prey. Entomol. Exp. Appl. 75, 27-31.

COCUZZA, G. E., DE CLERCQ, P., VAN DE VEIRE, M., DE COCK, A., DEGHEELE, D. and VACANTE, V., 1997. Life tables and predation activity of *Orius laevigatus* and *O. albidipennis* at three constant temperatures. Entomol. Exp. Appl. 85, 189-198.

COHEN, A. C. and BYRNE, D. N., 1992. *Geocoris punctipes* as a predator of *Bemisia tabaci*: a laboratory evaluation. Entomol. Exp. Appl. 64, 195-202.

COHEN, A. C., 1984. Food consumption, food utilization, and metabolic rates of *Geocoris punctipes* (Het.: Lygaeidae) fed *Heliothis virescens* (Lep.: Noctuidae) eggs. Entomophaga. 29(4), 361-367.

CROCKER, R. L., WHITCOMB, W. H. and RAY, R. M., 1975. Effects of Sex, developmental stage and temperature on predation by *Geocoris punctipes*. Environ. Entom. 4(4), 531-534.

DAVIS, J. R. and KIRKLAND, R. L., 1982. Physiological and environmental factors related to the dispersal flight of the convergent lady beetle, *Hippodamina convergens* (GUERIN-MENEVILLE). J. Kans. Entomol. Soc. 55, 187-196.

DE CLERCQ, P. and DEGHEELE, D., 1993. Cold storage of the predatory bugs *Podisus maculiventris* (SAY) and *Podisus sagitta* (FABRICIUS) (Heteroptera: Pentatomidae). Parasitica 49, 27-41.

DEANGELIS, J. D., SETHER, D. M. and ROSSIGNOL, P. A., 1994. Transmission of impatiens necrotic spot virus in peppermint by western flower thrips (Thys., Thripidae). J. Econ. Entomol. 87, 197-201.

DELIGEORGIDIS, P. N., 2002. Predatory effect of *Orius niger* (WOLFF) (Hem., Anthocoridae) on *Frankliniella occidentalis* (PERGANDE) and *Thrips tabaci* LINDEMAN (Thysan., Thripidae). J. Appl. Ent. 126, 82-85.

DENG, D. A., 1982. Experiments on feeding with artificial diets and cold storage of *Leis axyridis* PALLAS. Insect Knowledge Kunchong Zhishi 19, 11-12.

DISSEVELT, M., ALTENA, K. and RAVENSBERG, W. J., 1995. Comparison of different *Orius* species for control of *Frankliniella occidentalis* in glasshouse vegetable crops in The Netherlands (*Orius majusculus*, *Orius niger*, *Orius albidipennis*, *Orius laevigatus*). Med. Fac. Landbouw. Rijksuniver. Gent (Belgium) 60(3), 839-845.

DOBBS, T. T. and BOYD, D. W., 2006. Status and distribution of *Montandoniola moraguesi* (Hemiptera: Anthocoridae) in the Continental United States. Florida Entomologist 89(1), 41-46.

DUNBAR, D. M. and BACON, O. G., 1972. Influence of temperature on development and reproduction of *Geocoris atricolor*, *G. pallens* and *G. punctipes* (Heteroptera: Lygaeidae) from California. Environ. Entom. 1(5), 596-599.

FRITSCHE, M. E. and TAMO, M., 2000. Influence of thrips prey species on the life-history and behaviour of *Orius albidipennis*. Entomol. Exp. Appl. 96, 111-118.

GABARRA, R., CASTAÑÉ, C. and ALBAJES, R., 1995. The mired bug *Dicyphus tamaninii* as a greenhouse whitefly and western flower thrips predator on cucumber. Bioc. Sci. Techn. 5, 475-488.

GILKESON, L. A., 1992. Cold storage of the predatory midge *Aphidoletes aphidimyza* (Diptera: Cecidomyiidae). J. Econ. Entomol. 83, 965-970.

GILLESPIE, D. R. and QUIRING, D. J. M., 1992. Competition between *Orius tristicolor* (WHITE) (Hemiptera: Anthocoridae) and *Amblyseius Cucumeris* (OUDEMANS) (Acari: Phytoseiidae) feeding on *Frankliniella occidentalis* (PERGANDE) (Thysanoptera: Thripidae). Can. Entomol. 124, 1123-1128.

GOMEZ, K. A. and GOMEZ, A. A., 1984. Statistical procedures for agricultural research 2nd ed. John Wiley and Sons, Inc., New York, USK. pp. 680.

GUILLEBEAU, L. P. and ALL, J. N., 1989. *Geocoris* spp. (Hemiptera: Lygaeidae) and the striped lynx spider (Araneae: Oxyopidae): Cross predation and prey preferences. J. Econ. Entom. 82(4), 1106-1110.

HAGLER, J. R., JACKSON, C. G., ISAACS, R. and MACHTLEY, S. A., 2004. Foraging behavior and prey interactions by a guild of predators on various lifestages of *Bemisia tabaci*. J. Insect Science 4(1), 1-13.

HANLON, C. C. and PAINE, T. D., 2003. Biological control of Cuban laurel thrips (Thysanoptera: Phlaeothripidae) in California. 1st International symposium on biological control of arthropods, FHTET-03-05, 474-478.

HUANG, X., ZHAO, P., ZHOU S. and CAI, W., 2007. A taxonomic review of genus *Scipinia stål* (Hemiptera: Reduviidae: Harpactorinae) from China. Zootaaxa 1507, 57-67.

KAKIMOTO, K., URANO, S., NODA, T., MATUO, K., SAKAMAKI, Y., TSUDA, K. and KUSIGEMATI, K., 2005. Comparison of the reproductive potential of three *Orius* species: *O. strigicollis*, *O. sauteri*, and *O. minutus* (Heteroptera: Anthocoridae), using eggs of the Mediterranean flour moth as a food source. Appl. Entomol. Zoll. 40, 247-255.

KAPADIA, M. N. and PURI, S. N., 1991. Biology and comparative predation efficacy of three Heteropteran species recorded as predators of *Bemisia tabaci* in Maharashtra. Bio. Control. 36 (4), 555-559.

KIM, J. H., KIM, Y. H., HAN, M. W., LEE, G. S. and LEE, J. O., 1999. Effect of temperature on the development and oviposition of minute pirate bug, *Orius strigicollis* (Hemiptera: Anthocoridae). Korean J. Appl. Entomol. 38, 29-33.

KOK, L. T. and MCAVOY, T. J., 1983. Refrigeration, a practical technique for storage of eggs of *Trichosirocalus horridus* (Coleoptera: Curculionidae). Can. Entomol. 115, 1537-1538.

KUMAR, N. S., ANANTHAKRISHNAN, T. N. and SURESH, K. N., 1985. *Geocoris ochropterus* FABR. as a predator of some thrips. Proc. Indian Nat. Sci. Acad. Biol. Sci. 51(2), 185-193.

LI C. X., JIANG L. N., SHAO Y., and WANG W. L., 2005. Biostatistique. Science Press. Beijing, China. Pp 80-89.

LIANG, M. D. and HU, C., 1989. Bionomics of *Telenomus theophilae*. Acta Ser. Sinica 15, 95-99.

LUCAS É., CODERRE, D. and BRODEUR, J., 1998. Intraguild predation among aphid predators: characterization and influence of extraguild prey density. Ecology 79 (1), 1084-1092.

LYKOURESSIS, D., PERDIKIS, D. and MICHALAKI, M., 2001. Nymphal development and survival

of *Macrolophus pygmaeus* RAMBUR (Hemiptera: Miridae) on two eggplant varieties as affected by temperature and presence/absence of prey. Biol. Control 20, 222-227.

MARCHOUX, G., GEBRE, S. K. and VILLEVIELLE, M., 1991. Detection of tomato spotted wilt virus and transmission by *Frankliniella occidentalis* in France. Plant Pathol. 40, 347-351.

MCDONALD, R. C. and KOK, L. T., 1990. Post refrigeration viability of *Pteromalus* puparum (Hymenoptera: Pteromalidae) within host chrysalids. J. Entomol. Sci. 25, 409-413.

MIAO, Y., ZHOU, Y., SUN, S., LIU, J. MENG, Q. and YE, C., 2002. Dynamics of predatory natural enemy community in cotton fields. Ying Yong Sheng Tai Xue Bao, 13(11), 1437-40.

MOREWOOD W. D., 1992. Cold storage of *Phytoseiulus persimilis* (Phytosiidae). Exp. Appl. Acarol. 13, 231-236.

MUKHOPADHYAY, A. & SANNIGRAHI, S., 1993. Rearing success of a polyphagous predator *Geocoris ochropterus* (Hem.: Lygaeidae) on preserved ant pupae of *Oecophylla smaragdina*. Entomophaga 38(2), 219-224.

MURAI, T., 2000. Effect of temperature on development and reproduction of the onion thrips, *Thrips tabaci* LINDEMAN (Thysanoptera: Thripidae), on pollen and honey solution. Appl. Entomol. Zool. 35(4), 499-504.

NAGAI, K. and YANO, E., 2000. Predation by *Orius sauteri* (POPPIUS) (Heteroptera: Anthocoridae) on *Thrips palmi* KARNY (Thysanoptera: Thripidae): Functional response and selective predation. Appl. Entomol. Zool. 35(4), 565-574.

NARANJO, S. E. and STIMAC, J. L., 1985. Development, survival, and reproduction of *Geocoris punctipes* (Hemiptera: lygaeidae): Effects of plant feeding on soybean and associated weeds. Environ. Entom. 14(4), 523-530.

PARAJULEE, M. N., SHRESTHA, R. B., LESER, J. F., WESTER, D. B. and BLANCO C. A., 2006. Evaluation of the functional response of selected arthropod predators on bollworm eggs in the laboratory and effect of temperature on their predation efficiency. Environ. Entom. 35(2), 379-386

PERDIKIS, D. and LYKOURESSIS, D., 2000. Effects of various items, host plants, and temperatures on the development and survival of *Macrolophus pygmaeus* RAMBUR (Hemiptera: Miridae). Biol. Control 17, 55-60.

ROSENHEIM, J. A., 2005. Intraguild predation of *Orius tristicolor* by *Geocoris* spp. and the paradox of irruptive spider mite dynamics in California cotton. Biol. Control 32, 172-179.

RUAN, C. Q., LIU Y., LIU, B. and ZHU, Y. J., 2008. Life table of the experimental population of predator *Scipinia subula* (Heteroptera: Reduviidae). Fujian J. Agric. Sci. 23 (1), 11-14.

RUDOLF, E., MALAUSA, J. C., MILLOT, P. and PRALAVARIO, R., 1993. Influence of cold temperature on biological characteristics of *Orius laevigatus* and *Orius majusculus* (Het.: Anthocoridae). Entomophaga 38, 317-325.

SAMPSON, C. and KING, V. J., 1996. *Macrolophus caliginosus*, field establishment and pest control effect in protected tomatoes. IOBC/WPRS Bull. 19(1), 143-146.

SANCHEZ, J. A. and LACASA, A., 2002. Modeling population dynamics of *Orius laevigatus* and *O. albidipennis* (Hemiptera: Anthocoridae) to optimize their use as biological control agents of *Frankliniella occidentalis* (Thysanoptera: Thripidae). Bull. Entomol. Res. 92(1), 77-88.

SENGONCA, C. and FRINGS, B., 1985. Interference and competitive behaviour of the aphid predators, *Chrysoperla carnea* and *Coccinella septempunctata* in the laboratory. Entomophaga 30, 245-251.

SENGONCA, C. and SALEH, A., 2002. Prey consumption of the predateory bug *Dicyphus tamaninii* WAGNER (Heteropotera: Miridae) during nymphal and adult stages by feeding on *Aphis gossipii* GLOVER (Homoptera: Aphididae) as prey. J. Plant Diseases Protection 109, 430-439.

SENGONCA, C., AHMADI, K. and BLAESER, P., 2008. Biological characteristics of *Orius similis* ZHENG (Heteroptera, Anthocoridae) by feeding on different aphid species as prey. J. Plant Diseases Protection 115(1), 32-38.

SENGONCA, C., AL-ZYOUD, F. and BLAESER, P., 2004. Life table of the entomophagous ladybird *Serangium parcesetosum* SICARD (Coleoptera: Coccinellidae) by feeding on *Bemisia tabaci* (GENN.) (Homoptera: Aleyrodidae) as prey at two different temperatures and plant species. J. Plant Diseases Protection 111(6), 598-609.

SENGONCA, C., AL-ZYOUD, F. and BLAESER, P., 2005. Prey consumption by larval and adult stages of the entomophagous ladybird *Serangium parcesetosum* SICARD (Col., Coccinellidae) of the cotton whitefly, *Bemisia tabaci* (GENN.) (Hom., Aleyrodidae), at two different temperatures. J. Pest. Sci. 78, 179-186.

SILVIA, I. R., CANTLIFFE D. J. and PRICE J. F., 2004. The feeding behavior of the bigeyed bug, and pink spotted lady beetle relative to main strawberry pests. Environ. Entomol. 33(4), 1014-1019.

SMITLEY D. R., 1992. Biological control of western flower thrips with *Orius*, a predaceous bug. Roses. Inc. Bull. 99(4), 59-64.

SUN B. C., 1993. Elementary study biology of *Geocoris pallidipennis* (Heteroptera : Lygaeidae). Nat. Enem. Insects 15(4), 157-159.

TANG, Q. Y., 2001. Data Processing System. Science Press, Beijing. 648 pp.

TOMMASINI, M. G. and MAINI, S., 1995. *Frankliniella occidentalis* and other thrips harmful to vegetable and ornamental crops in Europe. Wageningen Agric. Univ. Papers 95, 1-43.

TOMMASINI, M. G., VAN LENTEREN, J. C. and BURGIO, G., 2004. Biological traits and predation capacity of four *Orius* species on two prey species. Bull. Insectol. 57(2), 79-93.

TORRES, J. B., SILVA-TORRES, C. S. A. and RUBERSON, J. R., 2004. Effect of two prey types on life-history characteristics and predation rate of *Geocoris floridanus* (Heteroptera: Geocoridae). Environ. Entom. 33(4), 964-974.

TRAUBE M. J., TAUBER, C. A. and GARDESCU, S., 1993. Prolonged storage of *Chrysoperla carnea* (Neuroptera: Chrysopidae). Environ. Entomol. 22, 843-848.

WEI, C. S., PEN, Z. J. and YANG G. Q., 1984. Elementary study biology of *Orius similis* (Heteroptera : Anthocoridae). Nat. Enem. Insects 6 (1), 32-40.

WHITAKER-DEERBERG, R. L., MICHELS, G. J., WENDEL, L. E. and FAROOQUI, M., 1994. The effect of short-term cold storage on emergence of *Aphelinus asychis* WALKER (Hymenoptera: Aphelinidae) mummies. Southwestern Entomol. 19, 115-118.

ZHANG, G. A., Zong, L. B., DUAN, H. H., XIONG, J. H., LU, R. Y. and XU, F. L., 1994. Spatial distribution of the flower bug, *Orius similis*, and its interaction with the pink bollworm, *Pectinophora gossypiella*, in cotton fields. Int. J. Pest Manag. 40(4), 309-312.

ZHAO, G., LIU, W. and KNOWLES, C. O., 1994. Mechanisms associated with diazinon resistance in western flower thrips. Pest. Biochem. Physiol. 49, 13-23.

ZHOU, X. M. and LEI, C. L., 2002. Utilization efficiency and functional response of *Orius similis* ZHENG (Hemiptera: Anthocoridae) to different preys. Acta Ecol. Sinica 22(12), 2085-2090.

ZONG, L. B., ZHONG, C. Z., LEI, Z. L., PENG, C. W. and WU, M. R., 1987. Predation efficacy of *Orius similis* on the eggs of pink bollworm, *Pectinophora gossypiella*. Chinese J. Biol. Control 3(2), 87.

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