Agriculture and Natural Resources 50 (2016) 380–387

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Predatory thrips species composition, their prey and host plant association in Northern Thailand

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ARTICLE INFO

Article history:
Received 27 January 2015
Accepted 25 October 2015
Available online 27 December 2016

Keywords:
Association
Biological control
Insect and mite pests
Occurrence
Predatory thrips

ABSTRACT

A survey of predatory thrips, their prey and associated host plants was carried out from February 2013 to February 2014 in Chiang Rai, Phayao, Chiang Mai, Lamphun and Lampang provinces in Northern Thailand. The survey revealed 10 species of predatory thrips in 5 genera in the Family Phlaeothripidae. They were: *Aleurodothrips fasciapennis* (Franklin), *Androthrips flavipes* Schmutz, *Androthrips ramachandrai* Karny, *Karnyothrips flavipes* (Jones), two indeterminate *Karnyothrips* sp.1 and sp.2, *Leptothrips* sp., *Podothrips lucasseni* (Krüger), and two indeterminate *Podothrips* sp. 1, and sp. 2. Eleven species of insect and mite pests serving as prey were found associated with 16 species of host plants in 13 families. They were: scale insects, *Coccus viridis* (Green) and two *Coccus* spp.; spiraling whitefly, *Aleurodicus dispersus* Russell; unidentified gall-making Hemiptera; coffee berry borer, *Hypothenemus hampei* (Ferrari); unidentified crambid lepidopterous larvae; Kanzawa spider mite, *Tetranychus kanzawai* Kishida; santol gall mite, *Eriophyes sandorici* Nelepa; litchi rust mite, *Aceria litchii* (Keifer); and bamboo green mite, *Aponychus corpuzae* Rimando. The findings from this investigation could provide basic information necessary for further investigation in the use of some of these predatory thrips as biological control agents of insect and mite pests of economic importance in Thailand.

Introduction

It is generally known and recognized that pest thrips are insect pests of economic importance in agricultural production and some thrips species such as the melon thrips—*Thrips palmi* Karny (Thysanoptera: Thripidae)—have been frequently intercepted in some vegetables and orchids exported from Thailand (Kajita et al., 1992; Collins, 2016). However, not adequately known is which of the predatory thrips are beneficial, serving as predators of small insect and mite pests and contributing to naturally occurring biological control of these arthropod pests. Unfortunately, they have been overlooked as renewable and valuable natural resources and they deserve further investigation and exploitation for augmentative biological control and extensive conservation.

Lewis (1973) compiled a list of predatory thrips and their prey in different countries from Thompson and Simmonds (1965) with amendments containing less than 30 species of predatory thrips. Kirk (1997) stated that some thrips are known as useful predators of mites and Lepidoptera on some field crops. A literature review covering predatory thrips in Thailand has yielded inadequate information of relevance. Hirose et al. (1989, 1993) and Okajima et al. (1992) conducted field surveys of thrips in Thailand, Malaysia and the Philippines during 1987–1988 in collaboration with Thai entomologists from the National Biological Control Research Center, Kasetsart University, Bangkok, Thailand. From the survey, 18 thrips species, including *T. palmi*, were recorded from solanaceous, cucurbitaceous and leguminous crops. Two predatory thrips found were the vespiform thrips, *Franklinothrips vespiformis* (Crawford) (Aeolothripidae) and *Scolothrips asura* Ayyar & Margabandhu (Thripidae). *F. vespiformis* was recorded from Okinawa, Japan in 1996 by Arakaki and Okajima (1998). It was also reported from California by Bethke et al. (2014). It attacks larvae and adults of *T. palmi*, two spider mite species, larvae of the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring or *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), and larvae of the serpentine leafminer, *Liriomyza trifolii* Burgess (Diptera: Agromyzidae). It was mass reared and used in southern France to supplement the predatory mite, *Neoseiulus cucumeris* (Oudemans) (Acarina: Phytoseiidae) to control onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), western flower thrips, *Frankliniella occidentalis* (Pergande) (Thripidae), and *Aeolothrips* spp. (Aeolothripidae) in rose greenhouses (Nammour et al., 2008).

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http://dx.doi.org/10.1016/j.anres.2015.10.002

Poonchaisri (2001) recorded a number of predatory thrips of the suborder Terebrantia in Thailand. They were *Aduncothrips asiaticus* Ramakrishna & Margabandhu, *Aeolothrips fasciatus* (L.), *F. vespiformis*, *Mymarothrips garuda* Ramakrishna & Margabandhu and *Rhipidothrips* sp. in the Family Aeolothripidae; and *S. asura* and *Scolothrips sexmaculatus* (Pergande) in the Family Thripidae.

A thrips survey was conducted during January–February 2005 in Chiang Mai, Thailand by Dr Mark S. Hoddle and Dr Christina Stosic of the University of California, Riverside, CA, USA together with the author. In this survey, a predatory thrips, *Androthrips flavipes* (Schmutz) (Phlaeothripidae) was found in association with four species of large black thrips in the Family Phlaeothripidae in leaf galls of Chinese banyan, *Ficus retusa* (Moraceae) consisting of *Gynaikothrips* sp., the Cuban laurel thrips, *Gynaikothrips ficorum* (Marchal), *Gigantothrips elegans* (Zimmerman), and *Mesothrips* sp.

Predatory thrips have been reported worldwide from the states of Arizona, California, Florida and Texas in the USA (North America), the Caribbean, Central and South America, Asia and the Pacific region, and Australia (Hirose et al., 1989, 1993; Okajima et al., 1992; Arakaki and Okajima, 1998; Mound and Reynaud, 2005). The predatory thrips thus reported were mostly vespiform thrips such as *Franklinothrips orizabensis* Johanson (Aeolothripidae) and *F. vespiformis*; six-spotted thrips, *S. sexmaculatus*; and black hunter thrips, *Leptothrips mali* (Fitch) (Phlaeothripidae) (Hoddle et al., 2001a; Hoddle, 2003; Mound and Reynaud, 2005).

A predatory thrips (*F. vespiformis*) was reported as a potential natural enemy of mites, leafhoppers and whiteflies in citrus and avocado orchards in Central and South America and it was used as a biological control agent for onion thrips, *T. tabaci,* in greenhouse rose (Moulton, 1932). Other predatory thrips such as *Aeolothrips* spp., *S. sexmaculatus* and *Leptothrips* spp. were reported as effective biological control agents (Johansen, 1983; Mound and Marullo, 1996, 1998). *F. orizabensis* was extensively studied for its mass rearing technique, and its biology and efficacy for biological control of avocado thrips, *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) (Hoddle et al., 2001a, 2001b, 2003, 2004). Mound and Reynaud (2005) reported that it has been marketed in Europe as a biocontrol agent against thrips in greenhouses. Dreistadt et al. (2004) in California, USA reported on the biological control potentials of some predatory thrips such as *Aeolothrips* spp., *L. mali*, *F. orizabensis*, *F. vespiformis* and *S. sexmaculatus* in controlling thrips pests, including avocado thrips, *S. perseae*; bean thrips, *Caliothrips fasciatus* (Pergunde); citrus thrips, *Scirtothrips citri* (Moulton); Cuban laurel thrips, *G. ficorum*; onion thrips, *T. tabaci* and western flower thrips, *F. occidentalis*, as well as mites, scale insects and lace bugs. Fathi et al. (2008) reported on the utilization of *Aeolothrips intermedius* Bagnall (Aeolothripidae) and *Orius niger* (Wolff) (Hemiptera: Anthocoridae) for the biological control of *T. tabaci* on potato.

The objective of this study was to investigate the occurrence of predatory thrips, their prey, host plant association and their distribution encountered in various ecosystems such as vegetables, horticultural and ornamental plants, fruit orchards, and forests in the upper northern region of Thailand in Chiang Rai, Phayao, Chiang Mai, Lamphun and Lampang provinces. The investigation also aimed to acquire basic information necessary for paving an approach to using predatory thrips as one of the biological control agents in the integrated pest management system.

Materials and methods

Field survey and collection

A field survey of predatory thrips and their prey consisting of insect and mite pests was carried out from February 2013 to February 2014 in the upper northern region of Thailand concentrating in Chiang Rai, Phayao, Chiang Mai, Lamphun and Lampang provinces. The region studied was located between latitudes 18°14′N and 19°54′N and longitudes 98°60′E and 99°49′E. The study areas in these provinces are characterized by a pattern of generally north-south steep Phi Pan Nam hill ranges, intermontane valleys and basins and alluvial gorges of the Ping, Wang and Yom Rivers which together with the Nan River are the four major tributaries of the Chao Phraya River. The altitude is moderate at 200–300 m above sea level at the floors of the valleys and basins to over 2000 m for higher mountainous areas with Doi Inthanon as the highest summit at 2565 m in the Chom Thong district of Chiang Mai province. The 1981–2010 average minimum and maximum temperature, rainfall and relative humidity in the provinces of Chiang Mai, Chiang Rai, Phayao, Lampang and Lamphun were: 14.9–24.0 °C to 30.1–35.2 °C; 12.8–23.6 °C to 27.2–34.8 °C; 13.7–24.0 °C to 27.8–36.0 °C; 15.0–24.1 °C to 30.2–38.0 °C; 14.3–24.0 °C to 30.0–36.7 °C for temperature; 4.2–216.9 mm; 7.5–358.4 mm; 5.7–204.0 mm; 2.8–186.0 mm; 2.8–172.7 mm for rainfall; and 52–81%; 62–84%; 58–84%; 57–83%; 54–83% relative humidity, respectively (Thai Meteorological Department, n.d.). The overall climatic pattern in these provinces is humid tropical during the warmer months and is temperate during the brief period of winter months.

The host plants examined were annual and perennial field crops, plantation crops, shrubs or trees, orchards, ornamental plants and roadside vegetation and weeds. The collection was in line with the method given by Lewis (1973) and Hoddle et al. (2002), that is, beating the plant parts (foliage or flowers) onto a white plastic tray (18 cm × 30 cm × 10 cm), then all dropped insects were removed from the tray using a fine, camel-hair brush and placed in 2 mL plastic Cryovial Non-Sterile (Sorenson BioScience, South West Salt Lake City, UT, USA) containing alcohol-glycerin-acetic acid (10 parts of 60% alcohol, 1 part of glycerin and 1 part of glacial acetic acid) or alcohol-glycerin-acetic acid (AGA) preservative (Mound and Pitkin, 1972). The plant extraction method of Lewis (1973) was also employed by dropping plant materials containing thrips into a screw-capped, plastic tube containing 50 mL of 70% ethanol and vigorously shaking the solution. All plant materials were then discarded and the alcohol wash was replaced with AGA preservative from a dropper and the specimens were then transferred into the plastic Cryovial. The locality, the date of collection and a concise description of the habitat and host plant were recorded together with global positioning system (Oregon-450′ Garmin; Kansas City, KS, USA) readings. All samples were brought back for laboratory processing and further study and identification.

Laboratory study and identification

The insect and mite specimens collected together with thrips by the two methods were sorted and kept together in Petri dishes. A rough sorting and preliminary identification were made under a stereo microscope. The density of predatory thrips and each prey species was recorded. Individual thrips were mounted in Canada balsam or Hoyer's mounting medium using the technique of Mound and Pitkin (1972) for identification. The methods of preservation and mounting thrips for microscopic examination and permanent storage as reported by Lewis (1973) were adopted, and a new method for preparing and mounting dark thrips specimens by maceration with KOH, dehydration by absolute ethanol, mounting by Hoyer's medium and desiccation for microscopic examination by Mirab-balou and Chen (2010) was also employed.

The identification of thrips specimens—both pest thrips and predatory thrips—was made using classical, traditional methods with a visual identification system of the external morphology using a microscope as reviewed and advocated by Mehle and Trdan

(2012). Various available dichotomous and pictorial keys and references employed in the identification were: Zimmerman (1948), Lewis (1973, 1997), Okajima (1990, 2006), Okajima et al. (1992), Jangvitaya (1993), Reyes (1994), Mound and Kibby (1998), Palmer et al. (1998), Hua (2000), Poonchaisri (2001), Mound (2005), Tripplehorn and Johnson (2005), Mound and Ng (2009), Mound et al. (2009); Mirab-balou et al. (2011) and Zhang et al. (2011). The voucher specimens of all thrips species obtained in the present investigation were deposited in the Natural Enemy Reference Collection of the Maejo University Biological Control Research Center (MJU–BCRC), Faculty of Agricultural Production, Maejo University, Chiang Mai, Thailand.

The plant species found as host plants of the pest thrips were identified using Neal (1965), Harada et al. (1987), Holm et al. (1997), Smitinand (2001), Randall (2012), and several others.

Results and discussion

Predatory thrips species composition and their prey

The present survey of predatory thrips composition, their prey and host plants in the upper northern region of Thailand revealed 10 species of predatory thrips in 5 genera in the Family Phlaeothripidae. They were: *Aleurodothrips fasciapennis* (Franklin), *A. flavipes* Schmutz, *Androthrips ramachandrai* Karny, *Karnyothrips flavipes* (Jones), indeterminate *Karnyothrips* sp.1 and sp.2, *Leptothrips* sp., *Podothrips lucasseni* (Krüger), indeterminate *Podothrips* sp. 1 and sp. 2. Preliminary data on respective predatory species, their prey, host plant association and localities are summarized in Table 1.

A. fasciapennis (Franklin)

A. fasciapennis was described from the West Indies and it is widely distributed in tropical and subtropical regions and is commonly referred to as the whitefly thrips (Lewis, 1973). It is predatory on scale insects, whiteflies and mites. It was found predating on *Thrips* spp. as follows: on “Ya kon cham khao” or Spanish needle (*Bidens pilosa*) in Chiang Kham and Phu Sang districts, Phayao province; on scale insect *Coccus* sp. (Hemiptera: Coccidae) on “Yi nam” (*Derris indica*), on spiraling whitefly *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae) and on “Makok” or hog plum (*Spondias pinnata*) in San Sai district, Chiang Mai province; and on Kanzawa spider mite *Tetranychus kanzawai* Kishida (Acari: Tetranychidae) and cassava (*Manihot esculenta*) in Ngao district, Lampang province. It is known as a useful biological control agent of Southern Chinese origin which should be subjected to further study as a promising biological control agent.

It was recorded as an immigrant in Hawaii, USA from the specimen taken from coconut from Honolulu intercepted at quarantine in San Francisco (Zimmerman, 1948). Its prey are: California red scale, *Aonidiella aurantii* (Maskell), purple scale, *Lepidosaphes beckii* (Newman) and Glover scale, *Lepidosaphes gloveri* (Packard) (Hemiptera: Diaspididae) in China; coconut scale, *Aspidiotus destructor* Signoret (Hemiptera: Diaspididae) in Fiji; palmetto scale, *Comstockiella sabalis* Comstock (Hemiptera: Diaspididae) (Hemiptera: Coccidae) in Bermuda; and Florida red scale, *Chrysomphalus aonidum* (L.) (Hemiptera: Diaspididae) and chaff scale, *Parlatoria pergandii* Comstock (Hemiptera Diaspididae) in the USA (Lewis, 1973). It was also recorded from Australia (Mound and Heming, 1991; Watson et al., 2000). In Florida, USA, it was collected for the first

Table 1
Predatory thrips, their prey and host plant association in the upper northern region of Thailand.

Predatory thrips species	Prey	Host plant	Location (district, province)
Aleurodothrips fasciapennis (Franklin)	*Thrips* spp. (Thysanoptera: Thripidae)	“Ya kon cham khao” or Spanish needle (*Bidens pilosa*, Asteraceae)	Chiang Kham, Phu Sang, Phayao
	Coccus sp. (Hemiptera: Coccidae	“Yi nam” (*Derris indica,* Fabaceae)	San Sai, Chiang Mai
	Spiraling whitefly, *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae)	“Makok” or hog plum (*Spondias pinnata,* Anacardiaceae)	San Sai, Chiang Mai
	Kanzawa spider mite, *Tetranychus kanzawai* Kishida (Acari: Tetranychidae)	Kanzawa spider mite, *Tetranychus kanzawai* Kishida (Acari: Tetranychidae)	Ngao, Lampang
Androthrips flavipes Schmutz	Unidentified gall-making Hemiptera	“Pra du ban” (*Pterocarpus indicus*, Leguminosae) and unknown plant species	Mae Tha, Lamphun San Sai, Chiang Mai Mae Tha, Lamphun
	Cuban laural thrips, *Gynaicothrips ficorum* (Marchal) (Thysanoptera: Phlaeothripidae)	Chinese banyan tree (*Ficus retusa*, Moraceae)	San Sai, Chiang Mai
	Anthocorid thrips predator *Montandoniola confusa* Streito and Matocq (Hemiptera: Anthocoridae)	Chinese banyan tree (*Ficus retusa*, Moraceae)	Mae Tha, Lamphun San Sai, Chiang Mai
	Unidentified gall-making Hemiptera	“Pra du ban” (*Pterocarpus indicus*, Leguminosae) and unknown plant species	Mae Tha, Lamphun San Sai, Chiang Mai
	Cuban laural thrips, *Gynaikothrips ficorum* (Marchal) (Thysanoptera: Phlaeothripidae)	Chinese banyan tree (*Ficus retusa*, Moraceae)	Mae Tha, Lamphun San Sai, Chiang Mai
Androthrips ramachandrai Karny	Anthocorid thrips predator *Montandoniola confusa* Streito and Matocq (Hemiptera: Anthocoridae)	Chinese banyan tree (*Ficus retusa*, Moraceae)	Mae Tha, Lamphun San Sai, Chiang Mai
Karnyothrips flavipes (Jones)	Green scale, *Coccus viridis* (Green) (Hemiptera: Coccidae)	Coffee (*Coffea arabica*, Rubiaceae)	Mae Chan, Mae Fa Luang, Chiang Rai
	Coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae)	Coffee (*Coffea arabica,* Rubiaceae)	Mae On, Mae Taeng, Chom Thong, Chiang Mai Mueang Pan, Lampang
Karnyothrips sp.1	*Thrips* spp. (Thysanoptera: Thripidae)	Garlic (*Allium sativum*, Alliaceae)	Chiang Dao, Chiang Mai Ngao, Lampang
		“Ya kon cham khao” or Spanish needle (*Bidens pilosa*, Asteraceae)	Chiang Kham, Phu Sang, Phayao

Table 1 (*continued*)

Predatory thrips species	Prey	Host plant	Location (district, province)
Karnyothrips sp.2	*Thrips* spp. (Thysanoptera: Thripidae)	"Ban mai ru roi pa" or wild globe amaranth (*Gomphrena celosiodes*, Amaranthaceae)	Chae Hom, Mueang Pan, Lampang
		"Phak pet thai) or sessile joyweed (*Alternanthera sessilis*, Amaranthaceae)	Chae Hom, Mueang Pan, Lampang
	Unidentified crambid larvae (Lepidoptera: Crambidae)	"Makok" or hog plum (*Spondias pinnata*, Anacardiaceae)	Li, Lamphun
Leptothrips sp.	*Thrips* spp. (Thysanoptera: Thripidae)	"Ya kon cham khao" or Spanish needle (*Bidens pilosa*, Asteraceae)	Chiang Kham, Phayao
		"Tin tukkae" (*Tridax procumbens*, Asteraceae)	Chom Thong, Chiang Mai
	Eriophyid mite, *Acalitus odoratus* Keifer (Acari: Eriophyidae)	"Sap suea" or Siam weed (*Chromolaena odoratum*, Asteraceae)	Mae Tha, Lamphun
Podothrips lucasseni (Krüger)	Santol gall mite, *Aceria sandorici* Nalepa (Acari: Eriophyidae)	"Kra thon" or santol (*Sandoricum koetjape*, Meliaceae)	Li, Lamphun
	Litchi mite, *Aceria litchi* (Keifer) (Acari: Eriophyidae)	Litchi (*Litchi chinensis*, Sapindaceae)	Mueang, Phayao
Podothrips sp. 1	*Thrips* sp. (Thysanoptera: Thripidae)	"Chingcho luang" (*Argyreia capitiformis*, Convolvulaceae) "Yan khon" (*Lepistemon binectariferum*, Convolvulaceae)	Phu Sang, Phayao
	Aphis sp. (Hemiptera: Aphididae)	"Ya kon cham khao" or Spanish needle (*Bidens pilosa*, Asteraceae)	Phu Sang, Phayao
Podothrips sp. 2	Bamboo green mite, *Aponychus corpuzae* Rimando (Acari: Eriophyidae)	Bamboo (*Bambusa* sp., Poaceae)	San Sai, Chiang Mai Li, Lamphun
	Eutetranychus sp. (Acari: Tetranychidae)	"Pra du ban" (*Pterocarpus indicus*, Leguminosae)	San Sai, Chiang Mai Li, Lamphun.

time from flowers in a mixed block of citrus varieties in Dade County (Childers and Bashear, 1992) and Childers and Nakahara (2006). In China, it was reported to prey on spider mite *Tetranychus cinnabarinus* (Boisduval) (Acari: Tetranychidae), whiteflies and psyllid on citrus (Hua, 2000); from Japan by Okajima (2006); from Sri Lanka by Tillekaratne et al. (2007); on the leaves of grape infested by *Planococcus citri* (Rosso) (Hemiptera: Pseudococcidae) from Iran (Mirabbalou and Chen, 2012); and from China and Southeast Asia (Dang et al., 2014). According to Kirk (1997), *A. fasciapennis* was reported as the most effective predator and probably the most important natural enemy of the California red scale (*A. aurantii*) on citrus in southern China by Beattie (1985) who recommended investigating the possibility of introducing it to Australia to improve biological control and *A. fasciapennis* was utilized in periodic and augmentative releases in Australia by attempting to rear it on eggs and crawlers of the Florida red scale (*C. aonidum*) and eggs of the rice moth *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae) (Watson et al., 2000). Also, *A. fasciapennis* was introduced from Java to Fiji for control of the coconut scale (*A. destructor*) on coconut, but then not released because a similar species was found to be present already (Taylor, 1935).

A. flavipes Schmutz

A. flavipes is an inquiline in leaf galls caused by gall-forming thrips. It was found in the leaf galls caused by the Cuban laurel thrips (*G. ficorum*) on Chinese banyan tree (*F. retusa*) and "Pra du ban" (*Pterocarpus indicus*) in Mae Tha district, Lamphun province and San Sai district, Chiang Mai province. It was found preying on eggs, first-instar and second-instar nymphs of *G. ficorum* and probably the young nymphs of the anthocorid thrips predator *Montandoniola confusa* inside the *Ficus* leaf galls.

A. flavipes was also found in galls caused by *Arrhenothrips ramakrishnae* Hood, *Schedothrips orientalis* (Ananthakrishnan), *Gynaikothrips flaviantennatus* Moult, and *Brachythrips dantahasta* Ramakrishna on various plants in India and was fed upon by the anthocorid *Montandoniella moraguesi* Puton (= *Montandoniella confusa* Streito and Matocq) feeding on the gall makers *G. flaviantennatus* and *S. orientalis* (Ananthakrishnan and Varadarasan, 1977). Although the biology of this genus is little known, Varadarasan and Ananthakrishnan (1981) and Raman and Ananthakrishnan (1984) reported *A. flavipes* to be the most effective predatory inquiline species as it is associated with at least 15 thrips galls of the Indian subcontinent as a predator of several leaf gall-forming thrips. Devasahayam and Koya (1994) reported A. *flavipes* as one of the natural enemies of the leaf gall thrips *Liothrips karnyi* (Bagnall) on black pepper (*Piper nigrum*) in Kerala, India. *A. flavipes* was also reported on black pepper and considered a predator of gall-inducing thrips in Sri Lanka (Tillekaratne et al., 2011). It was also recorded from China and Southeast Asia by Dang et al. (2014).

A. ramachandrai Karny

A. ramachandrai is another inquiline in banyan leaf galls caused by *G. ficorum* and other gall-inducing thrips. It was collected from Mae Tha district, Lamphun province and San Sai district, Chiang Mai province. It was also found feeding on eggs, first-instar and second-instar nymphs of *G. ficorum* and probably the predaceous anthocorid *M. confusa* as well.

According to Boyd and Held (2006), *A. ramachandrai* was described from India by Karny (1926). It was found in association with gall-making thrips, *Austrothrips cochinchinensis* Karny (Thysanoptera: Phlaeothripidae) on "Man" (*Cordia cochinchinensis*) "Khao tok taek" (*Getonia floribunda*) and was also known from Thailand (Ananthakrishnan, 1978; Ananthakrishnan and Raman, 1989). It was considered an exotic thrips, assumed to be predaceous and associated with gall-inducing thrips and was first collected from Florida, USA in March 2002 and in Riverside, California, USA in August 2002. It was intercepted during a federal foreign-quarantine inspection along with *G. elegans* Zimmermann and *Gynaikothrips malabaricus* Ramakrishna on *Ficus* spp. imported from Nong Nooch Tropical Botanical Garden in Thailand. It is

considered a congener of predatory *A. flavipes* and considered having potential to be a beneficial biological control agent but a hindrance to weed biological control (Boyd and Held, 2006). However, such a hindrance by citing Reimer (1988) on using *Liothrips urichi* Karny (Phlaeothripidae) for biological control of the weed Koster's curse (*Clidemia hirta*) in Hawaii as a biotic interference was experimental and highly speculative. *A. ramachandrai* was recorded on *F. retusa* from China (Hua, 2000). It was also recorded from Mexico, Puerto Rico, Costa Rica and Colombia (Boyd and Held, 2006) and also recorded in leaf galls of *Ficus benjamina* caused by *Gynaikothrips uzeli* (Zimmermann) from Argentina (de Borbon and Agostini, 2011).

K. flavipes (Jones)

Three *Karnyothrips* spp. were found in the present survey, namely, *K. flavipes*, indeterminate *Karnyothrips* sp. 1 and sp. 2. *K. flavipes* was found feeding on the green scale *Coccus viridis* (Green) (Hemiptera: Coccidae) on coffee (*Coffea arabica*) in Mae Chan and Mae Pha Luang districts of Chiang Rai province. It was also found predating on eggs and young larvae of the coffee berry borer *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae) as reported earlier in Kenya by Vega et al. (2009) in Mae On, Mae Taeng and Chom Thong districts, Chiang Mai province and in Mueang Pan district, Lampang province.

K. flavipes is one of the most abundant predatory thrips reported worldwide and is commonly referred to as the black thrips. It was described from California, USA and is probably of southern USA origin but is now cosmopolitan in the tropics and sub-tropics. It was also recorded as *Trichothrips ripicola* Preisner in Trinidad as a blood-sucking thrips by Franklin (1908) and Williams (1921). It has been recorded from Hawaii as *Haplothrips* (*Karnyothrips*) *flavipes* by Moulton (1932, 1936) and Bianchi (1945), as *K. flavipes* by Bianchi (1946), and as an immigrant in Hawaii by Zimmerman (1948). Vega et al. (2009) reported *K. flavipes* as a predator of eggs and larvae of the coffee berry borer *H. hampei* in Kenya.

K. flavipes was recorded to predate on scale insect such as: the pit scales, *Asterolacanium* spp. (Hemiptera: Asterolecanidae); the chaff scales, *Parlatoria* spp. (Hemiptera: Diaspididae); and several black scales, *Saissetia* spp. (Hemiptera: Coccidae) in the Mediterranean region; and the camphor scale, *Pseudaonidia duplex* (Cockerell) (Hemiptera: Diaspididae) in the USA (Lewis, 1973). Pitkin (1976) added whiteflies and mites infesting citrus trees and other plants as prey of *K. flavipes*. In Florida, USA, Childers and Nakahara (2006) reported *K. flavipes* as one of seven predators together with *A. fasciapennis* and *Karnyothrips melaleucus* within citrus orchards harboring 21 plant-feeding thrips species and 8 fungus-feeding thrips species, and *K. flavipes* and *A. fasciapennis* were among the five most abundant thrips species collected within citrus tree canopies, not on vines or ground cover plants of 58 species in 26 families.

Karnyothrips sp.1 and sp.2

In addition to *K. flavipes*, two indeterminate *Karnyothrips* spp. were found. *Karnyothrips* sp.1 was found feeding on *Thrips* spp. on garlic (*Allium sativum*) in Chiang Dao district, Chiang Mai province and Ngao district, Lampang province and on "Ya kon cham khao" or Spanish needle (*B. pilosa*) in Chiang Kham and Phu Sang districts of Phayao province. *Karnyothrips* sp.2 was found feeding on *Thrips* spp., on "Ban mai ru roi pa" or wild globe amaranth (*Gomphrena celosiodes*) and on "Phak pet thai" or sessile joyweed (*Alternanthera sessilis*) in Chae Hom and Mueang Pan districts, Lampang province and on unidentified crambid larvae (Lepidoptera: Crambidae) feeding on "Makok" or hog plum (*S. pinnata*) in Li district, Lamphun province.

Hoddle et al. (2012) reported that about 45 species are listed in the genus *Karnyothrips*, but it is questionable how many of these should be placed in the same genus. Reyes (1994) prepared a key for the Philippine species of *Karnyothrips* consisting of *Karnyothrips ateuchis* Reyes, *Karnyothrips expandosus* Reyes, *K. flavipes* (Jones) and *K. melaleucus* (Bagnall). Mound and Marullo (1996) prepared a key for 14 species from Central and South America while a key to 11 species from Japan was given by Okajima (2006). Wang et al. (2013) prepared a key to four species of the genus *Karnyothrips* from China, namely, *Karnyothrips cyathomorphus* Wang, Mirab-balou & Tong, *K. flavipes*, *K. melaleucus* and *Karnyothrips robustus* Okajima. Further attempts are required to have the two indeterminate *Karnyothrips* spp. in the current study identified.

Leptothrips sp.

An indeterminate *Leptothrips* spp. was found preying on *Thrips* spp. on "Ya kon cham khao" or Spanish needle (*B. pilosa*) in Chiang Kham district, Phayao province, on "Tin tukkae" (*Tridax procumbens*) in Chom Thong district, Chiang Mai province and on eriophyid mite, *Acalitus odoratus* Keifer (Acari: Eriophyidae) on "Sap suea" or Siam weed *(Chromolaena odoratum*) in Mae Tha, Lamphun province. Morphologically *Leptothrips* sp. found in this study closely resembles the black hunter thrips, *L. mali* (Fitch) which is a temperate species and is considered the most economically valuable predatory thrips in eastern USA orchards and it is solitary in habit but very active with its predatory potential limited by its low reproduction because females are known to lay only one or two eggs (Hull and Horsburgh, 2014).

P. lucasseni (Krüger)

P. lucasseni was found preying on santol gall mite, *Aceria sandorici* Nalepa (Acari: Eriophyidae) on "Kra thon" or santol (*Sandoricum koetjape*) in Li district, Lamphun province, and on litchi mite, *Aceria litchi* (Keifer) (Acari: Eriophyidae) on litchi (*Litchi chinensis*) in Mueang district, Phayao province.

P. lucasseni is of tropical Asian origin and wide spread across Asia from the Indian subcontinent to northern Australia (Sen et al., 1988; Hoddle et al., 2012). It was recorded on sugarcane in Hawaii, USA by Bianchi (1946). Zimmerman (1948) reported *P. lucasseni* as an immigrant in Hawaii, USA and found it in sugarcane as a predator on sugarcane stalk mite, *Tarsonemus spinipes* Hirst or *Steneotarsonemus bancrofti* (Michael) (Acari: Tarsonemidae) and it was widespread in Indo-Pacific regions. Okajima (1978) recorded *P. lucasseni* from Thailand, Malaysia and Indonesia. Reyes (1994) also recorded *P. lucasseni* in the Philippines and Java in Indonesia. Hua (2000) listed it from China as *Kentronothrips lucasseni* but Dang et al. (2014) merely listed *Podothrips* as one of the Phlaeothripinae genera from China and Southeast Asia.

Podothrips sp.1 and sp. 2

Two indeterminate *Podothrips* spp. were also found in the present survey, namely, *Podothrips* sp.1 and *Podothrips* sp. 2. *Podothrips* sp.1 was found preying on *Thrips* spp. on "Chingcho luang" (*Argyreia capitiformis*) and on *Aphis* sp. (Hemiptera: Aphididae) on "Yan khon" (*Lepistemon binectariferum*) and "Ya kon cham khao" or Spanish needle (*B. pilosa*) in Phu Sang district, Phayao province. *Podothrips* sp. 2 was found preying on bamboo green mite, *Aponychus corpuzae* Rimando (Acari: Eriophyidae) on bamboo (*Bambusa* sp.) and a tetranychid mite, *Eutetranychus* sp. (Acari:

Tetranychidae) on "Pra du ban" (*P. indicus*) in San Sai district, Chiang Mai and in Li district, Lamphun province.

Ritchie (1974) listed more than 30 species of this genus from the Old World but only four species were reported in Central and South America (Mound and Marullo, 1996). Okajima (1978) described *Podothrips bellatulus* Okajima as a new species using a female specimen collected from bamboo leaf in Phuket, Thailand as a holotype and *Podothrips ferrugineus* Okajima from Malaysia assigning two male specimens collected from Phuket as its paratypes. *P. lucasseni* and *Podothrips* spp. are cosmopolitan predatory thrips species widespread across Asia from Pakistan to northern Australia and also Hawaii, USA and North America.

The *Podothrips* spp. found in this study are likely to be a promising biological control agent of some economic eriophyid and tetranychid mite pests such as the santol gall mite, *Eriophyes sandorici*, and the rust mite, *A. litchi,* on litchi.

Other predatory thrips

Of the predatory thrips found in the present survey, *A. flavipes* was earlier collected in Chiang Mai in 2005 (M.S. Hoddle and C. Stosic, personal communication). However, the ant-mimicking vespiform thrips, *F. vespiformis* and predatory *S. asura* reported from Thailand by Hirose et al. (1989, 1993) and Okajima et al. (1992) were not found. In addition, other predatory thrips recorded by Poonchaisri (2001) consisting of *A. asiaticus*, *A. fasciatus*, *M. garuda*, and *Rhipidothrips* sp. of the Family Aeolothripidae and *S. sexmaculatus* of the Family Thripidae were also not found in this preliminary survey.

Host plant association

In this study, 10 species of predatory thrips were found as the natural enemies of at least 11 prey species which are insect and mite pests infesting 16 species of crop plants, trees, fruit trees, vegetation and weeds in 13 families. Almost all predatory thrips species thus found could be detected more or less all year round in the upper northern region.

Field observation during the survey revealed that some predatory thrips species were commonly associated with prey found on shrubs or trees and some crops as well as roadside vegetation and weeds. *A. fasciapennis, A. flavipes* and *A. ramachandrai* were mostly found associated with "Pra du ban" (*P. indicus*), Chinese banyan tree (*F. retusa*) and unknown plant species in Phayao, Chiang Mai, Lampang and Lamphun provinces. *K. flavipes* was associated mainly with plantation crops such as coffee in Chiang Rai, Chiang Mai and Lampang provinces. *Karnyothrips* sp.1 was mostly encountered as a predator of thrips on garlic (*A. sativum*) and "Ya kon cham khao" or Spanish needle (*B. pilosa*) in Lampang and Phayao provinces, while *Karnyothrips* sp.2 was found preying on pest thrips associated with and restricted to amaranth weeds such as "Ban mai ru roi pa" or wild globe amaranth (*G. celosiodes*) and "Phak pet thai" or sessile joyweed (*A. sessilis*) in Lampang and Lamphun provinces. However, incidentally it was found preying on unidentified crambid larvae (Lepidoptera: Crambidae) on "Makok" or hog plum (*S. pinnata*) in Lamphun province. *Leptothrips* sp. was found with thrips pests inhabiting asteraceous weeds such as "Ya kon cham khao" or Spanish needle (*B. pilosa*) and "Tin tukkae" (*T. procumbens*), and with eriophyid mite on "Sap suea" or Siam weed (*C. odoratum*). *P. lucasseni* was quite common on eriophyid mites on "Kra thon" or santol (*S. koetjape*) in Lamphun province and litchi (*Litchi chinensis*) in Phayao province. *Podothrips* sp. 1 was associated with thrips on the vine "Chingcho luang" (*A. capitiformis*) and aphid on "Yan khon" (*L. binectariferum*) and "Ya kon cham khao" or Spanish needle (*B. pilosa*) in Phayao province. However, *Podothrips* sp. 2 was in association with bamboo eriophyid green mite, *A. corpuzae*, on bamboo (*Bambusa* sp.) and tetranychid mite, *Eutetranychus* sp. on "Pra du ban" (*P. indicus*) in Lamphun province.

In citrus orchards in Florida, USA, Childers and Nakahara (2006) recorded seven predatory thrips species associated with several weed species including "Phak khom nam" or spiny amaranth (*Amaranthus spinosus*), Mexican tea (*Dysphania ambrosioides*), "Kon cham" or Spanish needle (*Bidens alba*), "Ya khat" or paddy's lucerne (*Sida rhombifolia*), solanaceous weed (*Solanum americanum*), "Phaka krong" or lantana (*Lantana camara*) and other vines and ground cover plants. The predatory thrips recorded were *A. fasciapennis*, *K. flavipes*, *K. melaleucus*, *Leptothrips cassia* (Watson), *Leptothrips macroocellatus* (Watson), *Leptothrips pini* (Watson) and *S. sexmaculatus*. From these recordings, it could be postulated that the predatory thrips are usually associated with their prey which are commonly found inhabiting various ground cover vegetation and weeds rather than the annual crops preferred by the pest thrips species.

Of the 10 predatory thrips species found, 4 are indeterminate and pending proper identification. They were found together with their prey and were in association with 16 species of host plants in 13 families. Several species of these predatory thrips, especially *A. fasciapennis*, *A. flavipes*, *A. ramachandrai*, *K. flavipes* and *P. lucasseni*, exhibit high potential as biological control agents in the natural regulation and suppression of various insect and mite pests of economic importance. The species that could be encountered more or less all year round in the upper northern region of Thailand were: *A. fasciapennis, A. flavipes*, *A. ramachandrai*, *K. flavipes*, *Karnyothrips* sp. 1 and sp. 2, *Leptothrips* sp., *P. lucasseni*, *Podothrips* sp 1. and sp. 2. Both intensive and extensive exploration of the predatory thrips fauna should be continued if their biological control potentials are to be investigated. From this investigation, at least one or more predatory thrips species such as *A. fasciapennis*, *A. flavipes*, *A. ramachandrai*, *K. flavipes* and *P. lucasseni* could be initiated for further investigation and exploitation as biological control agents in augmentative biological control and appropriate conservation and more particularly as one of the pest management strategies within the concept of an integrated pest management system.

Conflict of interest

None.

Acknowledgements

The author would like to thank: the National Science and Technology Development Agency (NSTDA), Thailand for partial financial support for this project; the National Biological Control Research Center (NBCRC), Kasetsart University, Bangkok and the MJU Biological Control Research Center (MJU-BCRC), Faculty of Agricultural Production, Maejo University, Chiang Mai, Thailand for laboratory facilities and logistic support.

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