ความหลากหลายของชนิดแตนเบียนและหนอนผีเสื้อศัตรูพืชในพื้นที่ปลูกพืชตระกูลกะหล่ำ ตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน

นายกิตติภูมิ จันทร์ศรี

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SPECIES DIVERSITY OF PARASITIC WASPS AND LEPIDOPTERAN PESTS
IN *Brassica* AGRICULTURAL AREAS
AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE

Mr. Kittipum Chansri

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Zoology
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Thesis Title	SPECIES DIVERSITY OF PARASITIC WASPS AND LEPIDOPTERAN PESTS IN *Brassica* AGRICULTURAL AREAS AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE
By	Mr. Kittipum Chansri
Field of Study	Zoology
Thesis Advisor	Assistant Professor Buntika Areekul Butcher, Ph.D.
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กิตติภูมิ จันทร์ศรี : ความหลากหลายของชนิดแตนเบียนและหนอนผีเสื้อศัตรูพืชในพื้นที่ปลูกพืชตระกูลกะหล่ำตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน (SPECIES DIVERSITY OF PARASITIC WASPS AND LEPIDOPTERAN PESTS IN *Brassica* AGRICULTURAL AREAS AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.บัณฑิกา อารีย์กุล บุทเชอร์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: อ. ดร.ชัชวาล ใจซื่อกุล, 202 หน้า.

ความสัมพันธ์ระหว่างแตนเบียนและแมลงอาศัย และความหลากหลายของแตนเบียน ได้ถูกศึกษาในพื้นที่ปลูกพืชตระกูลกะหล่ำ ตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน ระหว่างเดือนตุลาคม 2555 – พฤศจิกายน 2556 ในช่วงฤดูกาลปลูกพืชตระกูลกะหล่ำ ผลการเลี้ยงหนอนผีเสื้อทั้ง 9 ชนิด ที่เก็บได้จากพืชตระกูลกะหล่ำ 5 ชนิด พบแตนเบียนที่สามารถเบียนหนอนผีเสื้อได้ทั้งหมด 13 ชนิด โดยหนอนกระทู้ผัก (*Spodoptera litera*) ซึ่งเป็นหนอนผีเสื้อแมลงศัตรูกลุ่มหลัก มีสหสัมพันธ์เชิงบวกกับความหลากหลายของชนิดพืชตระกูลกะหล่ำที่ปลูก และพบจำนวนสูงสุด 779 ตัว ในเดือนตุลาคม 2556 ความชุกชุมของแตนเบียน *Microplitis* sp. มีสหสัมพันธ์เชิงบวกต่อความชุกชุมของหนอนกระทู้ผัก และมีอัตราการเบียนสูงในเดือนมีนาคม ตุลาคม และพฤศจิกายน 2556 (25% 18.9% และ 18% ตามลำดับ) ความหลากหลายของชนิดและจำนวนตัวของหนอนผีเสื้อศัตรูพืชตระกูลกะหล่ำมีผลต่อความหลากหลายของชนิดและจำนวนตัวของแตนเบียน ในการทดลองศึกษาสหสัมพันธ์ระหว่างแตนเบียนและแมลงอาศัย ขนาดของพื้นที่ปลูกพืชตระกูลกะหล่ำมีสหสัมพันธ์เชิงบวกต่อความหลากหลายของชนิดแตนเบียนในมีประโยชน์ในการศึกษาด้วยกับดัก ซึ่งไม่มีความแตกต่างทางสถิติของจำนวนระหว่างช่วงในและนอกฤดูกาลปลูก กลุ่มแตนเบียนที่มีรายงานว่าสามารถเบียนหนอนผีเสื้อจำนวน 24 กลุ่ม สามารถพบได้ในกับดักทั้ง 4 ชนิด กับดัก Malaise มีประสิทธิภาพสูงสุดในการจับแตนเบียน โดยแตนเบียนวงศ์ย่อย Microgastrinae มีค่าความชุกชุมที่สูง และไม่มีความแตกต่างทางสถิติของจำนวนตัวอย่างระหว่างฤดูกาลปลูก ความหลากหลายของชนิดและขนาดของพื้นที่การปลูกพืชตระกูลกะหล่ำยังมีสหสัมพันธ์เชิงบวกต่อความหลากหลายของแตนเบียนอีกด้วย

ภาควิชา	ชีววิทยา	ลายมือชื่อนิสิต	....
สาขาวิชา	สัตววิทยา	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
ปีการศึกษา	2557	ลายมือชื่อ อ.ที่ปรึกษาร่วม	....

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KITTIPUM CHANSRI: SPECIES DIVERSITY OF PARASITIC WASPS AND LEPIDOPTERAN PESTS IN *Brassica* AGRICULTURAL AREAS AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE. ADVISOR: ASST. PROF. BUNTIKA AREEKUL BUTCHER, Ph.D., CO-ADVISOR: CHATCHAWAN CHAISUEKUL, Ph.D., 202 pp.

Host-parasitoid interactions and diversity of parasitic wasps were investigated in three *Brassica* agricultural areas at Lainan Subdistrict, Wiang Sa District, Nan Province, started from October 2012 – November 2013. During the *Brassica* cultivated seasons, thirteen species of beneficial parasitoids were recorded from rearing nine lepidopteran pests which collected from five cultivars of *Brassica* crops. *Spodoptera litura* was the major lepidopteran pest, with the highest number of individuals collected in October 2013 (779 individuals). Its abundance was positively correlated to varieties of *Brassica* cultivars. The abundance of parasitoids, *Microplitis* sp. was positively correlated to the abundance of *S. litura* with high parasitism rates in March, October and November 2013 (25%, 18.9% and 18%, respectively). Diversity and total number of lepidopteran pests affected the varieties and total number of parasitoids in hosts and parasitoids rearing methods, while the *Brassica* cultivation area was positively correlated to diversity of beneficial parasitoids in trap samplings, with no significant difference of the beneficial parasitoids abundance between the cultivated seasons. Four trap sampling methods collected 24 taxa of the parasitic wasps which parasitized the lepidopteran hosts. Malaise traps had the highest effectiveness for collecting parasitic wasps. The most abundance group of parasitoids found in the trap sampling was Microgastrinae with no significant difference in their number between the cultivated seasons. Varieties of *Brassica* cultivars and *Brassica* cultivation area were positively correlated to the diversity of parasitic wasps.

Department:	Biology	Student's Signature	....
Field of Study:	Zoology	Advisor's Signature	....
Academic Year:	2014	Co-Advisor's Signature	....

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Most meaningful, I would like to deliver my gratefulness to my family, for their love, nurture and moral support. Finally, I would like to dedicate this thesis to my parents and all of the persevere people.

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CHAPTER 1
INTRODUCTION

1.1 Rationale

Brassica crops are important green leafy vegetables in the family Brassicaceae (Cruciferae) (Koch, Al-Shehbaz et al. 2003), originating in the Mediterranean regions. Nowadays *Brassica olearacea* L., *Brassica rapa* L., *Brassica carinata* A. Braun, *Brassica juncea* (L.) Czern & Coss and *Brassica napus* L. are cultivated worldwide (Rakow 2004). In Southeast Asia, the *Brassica* cultivars have been grown all year round in both lowlands and highlands (Talekar and Shelton 1993, Sivapragasam 2004). Phytophagous pests, especially aphids, thrips, flea beetles and lepidopteran pests, are the major cause of *Brassica* yield loss, leading to high production costs and environmental contamination due to the use of chemical insecticides (Bonnemaison 1965, Zalucki, Shabbir et al. 2012).

The lepidopteran pests and the *Brassica* crops are closely related, and their host searching behavior, host plants selection, fecundity, mortality and development were influenced and affected by the chemical compounds of *Brassica* (Thorsteinson 1953, David and Gardiner 1966, Chew 1977, Renwick and Radke 1987, Thompson 1988, Talekar and Shelton 1993, Ibrahim, Nissinen et al. 2005, Kahuthia-Gathu, Löhr et al. 2008). In Southeast Asia, several species of lepidopteran pests were reported; namely, *Plutella xylostella, Pieris rapae, Pieris brassicae, Hellula undalis, Spodoptera litura, Crocidolomia pavonana* and others. (Keinmeesuke, Vattanatangum et al. 1992, Loke, Lim et al. 1992, Rowell, Jeerakan et al. 1992, Sastrosiswojo and Setiawati 1992, Sivapragasam and Chua 1997, Rowell, Bunsong et al. 2005, Fraser, Dytham et al. 2008, Maung, Tun et al. 2011, Soysouvanh 2011). The strategies of integrated pest management (IPM) were reported in these regions; such as cultural practice, the use of microbial and insecticide controls, introduced and established of natural enemies and the incorporation of parasitoids had been conducted (Sivapragasam 2004).

In *Brassica* cultivation areas, the abundance of beneficial parasitoids were reported in field observation and rearing in laboratory experiments. *Cotesia plutellae*, *Diadegma semiclasum* and *Diadromus collaris* were reported as successful parasitoids of *P. xylostella*, whereas, *Spodoptera litura* was parasitized by *Microplitis manila* and was recorded with the hyperparasitism of Mesochonid wasps (Rowell, Jeerakan et al. 1992). Moreover, terrestrial insect sampling methods has been used to evaluate the diversity and abundance of beneficial parasitic wasps in *Brassica* cultivation areas. Seventeen families of parasitoids were reported; including Bethylidae, Braconidae, Chalcididae, Cerephronidae, Diapriidae, Encytidae, Eulocilidae, Eupelmidae, Ichneumonidae, Megaspilidae, Mutillidae, Mymaromatidae, Platigastridae, Pteromalidae, Scelionidae, Torymidae and Trichogrammatoidae (Yaherwandi 2012, Yaherwandi and Hidrayani 2014). Malaise traps and yellow pan traps were highly effective sampling methods for the families Ichneumonidae and Braconidae (Noyes 1989, Idris, Zaneedarwaty et al. 2001). Moreover, light traps and netting were also recommended to collect the parasitic wasps (Grootaert, Pollet et al. 2010).

In Thailand, *P. xylostella* and *S. litura* are reported as the major pests of *Brassica* crops in Chiang Mai Province (Rowell, Jeerakan et al. 1992). Information of beneficial parasitoids diversity and their abundance are completely evaluated with the high abundance of *Cotesia plutellae* (Rowell, Jeerakan et al. 1992, Rowell, Bunsong et al. 2005). In Nan Province, the cabbages, *Brassica oleracea* L. var. *capitata* L., cauliflowers, *B. oleracea* L. var. *botrytis* L., Chinese kales, *B. oleracea* L. var. *alboglabra* Bailey, broccoli, *B. oleracea* L. var. *italic;* pak choi, *B. chinensis* Jusl var. *parachinensis* (Bailey) Tsen & Lee, Chinese cabbages, *B. rapa* L. var. *pekinensis* (Lour) Olsson, and leaf mustards, *B. juncea* L. var. *rugosa* (Roxb) Tsen & Lee, were cultivated approximately 700 ha in 2010 (NDOA 2010, NDOA 2011). More than 10 tons of insecticides had been applied in the vegetation farms in Nan Province (Chanphong 2008). However, there was no information on the diversity and abundance of lepidopteran pests and their associated parasitoids in this locality, and this information is necessary for the implementation of environmentally, friendly and sustainable integrated pest management in *Brassica* cultivation.

1.2 Objectives

The aims of this research are: 1) to study species diversity and abundance of lepidopteran pests in *Brassica* cultivation areas at Lainan Subdistrict, Wiang Sa District, Nan Province; 2) to study species diversity, abundance and parasitism rates of beneficial parasitoids of the lepidopteran pests; 3) to study the diversity of parasitic wasps in *Brassica* cultivation areas at Lainan Subdistrict, Wiang Sa District, Nan Province; and 4) to study the relationships among some climatic factors (such as temperature, humidity and rainfall), *Brassica* crops, lepidopteran pests and parasitoids.

1.3 Scope of study

The scope of this study involved the measurement of biological and physical factors, such as *Brassica* cultivars, lepidopteran pests, parasitoids, climatic factors, and field management. The study was conducted in three lowland *Brassica* cultivation farms at Lainan Subdistrict, Wiang Sa District, Nan Province, during and between *Brassica* cultivated seasons (October 2012 – November 2013). To study the species diversity and abundance of lepidopteran pests, the larvae and pupae of moths and butterflies were collected 2 days per month. The lepidopteran pests were reared in the laboratory, to collect the beneficial parasitoids that emerged from the caterpillars and their parasitism rates were also recorded. Malaise traps were conducted every week, while the mobile bucket light traps, yellow pan traps and aerial net were sampled two days (or nights) per month. In the *Brassica* fields, beneficial parasitoids and other parasitic wasps were collected using Malaise traps, mobile bucket light traps, yellow pan traps and aerial net. Lepidopteran pests, parasitic wasps and their relationships were analyzed using the prevalence and diversity indices. Finally, the physical and biological factors recorded from the experiment compared among the cultivated seasons (t-test), the study sites (Kruskall-Wallis) and their correlation (Spearman correlation) (Figure 1-1).

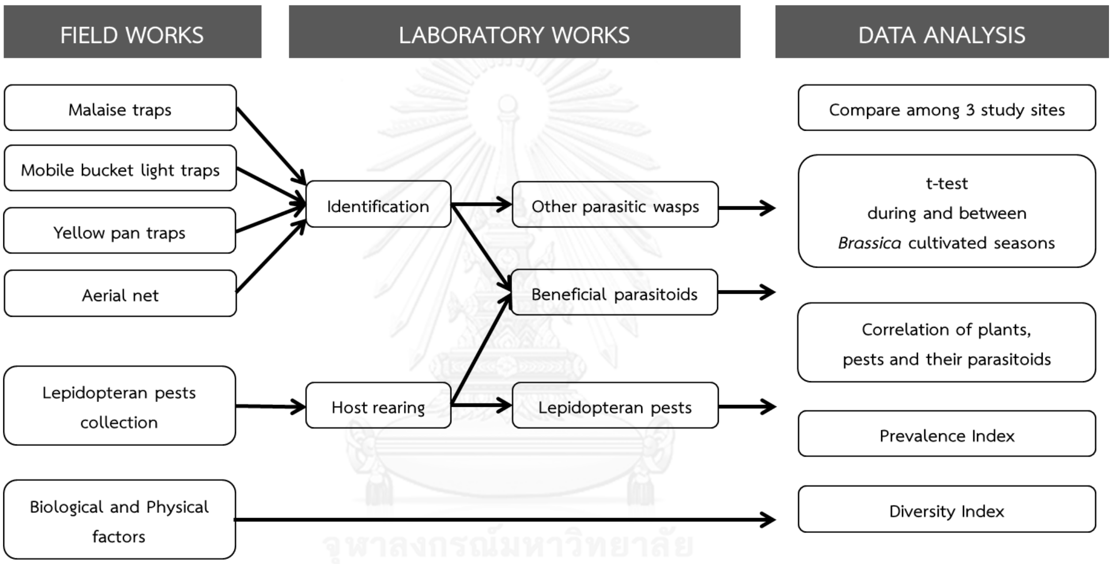

Figure 1-1 Scope of this research

CHAPTER 2
LITERATURE REVIEW

2.1 The *Brassica* cultivation

Brassica is a genus of the mustard plants in the family Brassicaceae (Cruciferae) (Koch, Al-Shehbaz et al. 2003). Originately from the Mediterranean regions, current species including: *Brassica nigra* (L.) Koch, *Brassica olearacea* L., *Brassica rapa* L., *Brassica carinata* A. Braun, *Brassica juncea* (L.) Czern & Coss and *Brassica napus* L. (Rakow 2004). Nowadays, *Brassica* is one of the important economical crops cultivated worldwide. In Southeast Asia, the *Brassica* crops are cultivated throughout the year in both lowlands and highlands of these regions (Talekar and Shelton 1993, Sivapragasam 2004). *Brassica* crops are attacked by a great variety of pests, such as dipteran, coleopteran, hemipteran and lepidopteran pests (Bonnemaison 1965, Kok and Pandalai 2004). Integrated Pest Management strategies (IPM), i.e. economic thresholds, incorporation of parasitoids, microbial application, selected insecticide and cultural practice, have been used in many countries, such as Malaysia (Loke, Lim et al. 1992), The Philippines (Eusebio and Morallo-Rejesus 1996) and Indonesia (Sastrosiswojo 1996).

In Thailand, about 800,000 tons of *Brassica* productions are produced on approximately 60,000 ha of *Brassica* cultivation areas in the lowlands and highlands of the country (Rowell, Bunsong et al. 2005). Rushtapakornchai and Vattanatangum (1986) reported that chemical insecticides failed to control the population of lepidopteran pests, due to the resistance of the pesticides. Yellow sticky traps have been used to control population of insect pests in the vegetation areas (Rushtapakornchai, Vattanatangum et al. 1992). For biological control, *Bacillus thuingiensis* (*BT*) had been used to control *Plutella xylostella* in Thailand since 1972. Moreover, *Diadegma semiclasum*, the parasitoids of *P. xylostella* were introduced from the Cameron Highland, Malaysia in 2005 and the introduction of parasitoids in 2005 – 2010 were shown to be succeeded in the Northeastern part of Thailand (Upanisakorn, Sammawan et al. 2011).

2.2 Lepidopteran pests

Larvae of butterflies and moths are the dominant phytophagous pests of *Brassica* crops. They are the major cause of *Brassica* productivity losses and lead to the high (production) costs for pest controls (Zalucki, Shabbir et al. 2012). Several studies of the lepidopteran pests on *Brassica* crop ecosystem showed that there are varieties of pest species, such as, *Plutella xylostella*, *Trichoplusia ni*, and *Pieris rapae*. (Foster 2001, Kok and Pandalai 2004, Badenes-Perez and Shelton 2006). The status of major and minor pests were defined by the percentage of crop yield loss (Misra and Sharma 1988). In tropical Asia, some important lepidopteran pests are reported in Table 2-1 (Lim, Sivapragasam et al. 1997). The abundance of lepidopteran pest species are different in the lowlands and highlands of the *Brassica* cultivation areas in the Southeast Asia.

Table 2-1 Status of the lepidopteran pests of the *Brassica* crops in tropical Asia (Lim, Sivapragasam et al. 1997)

Relative importance	Lepidopteran pest species
Very important	*Plutella xylostella*
	Pieris rapae
	Pieris brassicae
	Hellula undalis
Moderately important	*Spodoptera litura*
	Crocidolomia pavonana
	Agrotis ypsilon

2.2.1 *Plutella xylostella*

Diamondback moths, *Plutella xylostella* (Lepidoptera: Ypeunomutidae), are one of the most important insect pests of the *Brassica* crops, this have been distributed worldwide (Chu 1986, Talekar and Shelton 1993). However, their range of host-plants are limited by the glucosides, the chemical compounds of the plants in the family Brassicaceae (Thorsteinson 1953). In Southeast Asia, the diamondback moths were reported as the major pests of *Brassica* crops in both lowlands and highlands of *Brassica* cultivation areas in several countries; Indonesia (lowland (Shepard and Barrion 1998) and highland (Sastrosiswojo and Setiawati 1992)); Malaysia (lowland (Loke, Lim et al. 1992) and highland (Ooi 1992)); The Philippines (Poelking 1992); Myanmar (Maung and Tun 2011) and Lao PDR (Soysouvanh 2011).

In Thailand, *P. xylostella* is the major lepidopteran pest of the *Brassica*. Information from the field studies showed that, there was the highly abundance of *Brassica* crops in the lowland of the Central region (Keinmeesuke, Vattanatangum et al. 1992), highland of Northeastern part (Keinmeesuke, Vattanatangum et al. 1992, Upanisakorn, Jeerapong et al. 2011, Upanisakorn, Sammawan et al. 2011) and both lowland and highland in the Northern region of the country (Rowell, Jeerakan et al. 1992, Rowell, Bunsong et al. 2005, Upanisakorn, Jeerapong et al. 2011). In addition, for the laboratory experiments, development and reproductive, temperature tolerance and *BT* resistance of *P. xylostella* were also reported (Sarnthoy, Keinmeesuke et al. 1989, Imai and Mori 1999, Shirai 2000).

2.2.2 *Pieris rapae* and *Pieris brassicae*

Small cabbage white butterflies, *Pieris rapae* (Lepidoptera: Pieridae) are reported with their closely relationship on their host-plant Brassicaceae (Richards 1940). The chemical compounds of *Brassica* lead to either acceptance or rejection of the host plant, similarly to the physiology and the treatments of host-plants had affected on *P. rapae* oviposition and development (Myers 1985, Renwick and Radke 1987). For the large cabbage white butterfly, *P. brassicae* (Lepidoptera: Pieridae), the compounds of glucosides on *Brassica* affect the development during the larva stages. In temperate zone, *P. rapae* is in diapauses during winter and the adult will be emerged in spring (Lasota and Kok 1989), whereas in the tropical areas, the development of this butterfly occurs throughout the year (Richards 1940). In Thailand, *P. brassica* is reported as a minor pest of the lowland *Brassica* cultivation areas at Chiang Mai Province (Rowell, Jeerakan et al. 1992).

2.2.3 *Hellula undalis*

A common lepidopteran pest of *Brassica*, cabbage webworm, *Hellula undalis* (Lepidoptera: Pyralidae) is reported to be a major pest in most tropical and some temperate countries (Sivapragasam and Chua 1997). In Taiwan, the seasonal of *H. undalis* was dominant during the hot wet summer months (Talekar and Lee 1985), however, the rainfall had no effect on the development of the immature stages. The studies of Youssef, Hammad et al. (1973) and Sivapragasam and Chua (1997) showed that the preference of egg oviposition of *H. undalis* were on the shoot more than leaf of *Brassica* crops. In contrast, the larvae tend to bored and stayed in the head, leaf petioles and stem of the plants and would concealed them from the natural enemies and give high survival rate during the rainfall periods.

In Southeast Asia, *H. undalis* was reported as major pests on the lowlands of the *Brassica* cultivation in Malaysia (Loke, Lim et al. 1992, Sivapragasam and Chua 1997) and also recorded as undefined status of pests in the Cameron Highland, Malaysia (Ooi 1979). In Northern Thailand, *H. undalis* was reported as the minor pest on the lowlands of *Brassica* cultivation areas at Chiang Mai Province (Rowell, Jeerakan et al. 1992).

2.2.4 *Spodoptera litera*

A sporadic pest, cotton leafworm, *Spodoptera litura* (Lepidoptera: Noctuidae) is one of the major lepidopteran pests of various species of the economic crops (Shepard and Barrion 1998, Ghumare and Mukherjee 2003, Capinera 2008, Xue, Pang et al. 2010). Development of *S. litura* is related to the temperature threshold (Rao, Wightman et al. 1989). Capinera (2008) reported that *S. litura* is highly abundant in the tropical regions, especially in Asia, Australia, and Oceania. For *Brassica* cultivation in Southeast Asia, *S. litura* is reported as the major pest in the lowlands of the Northern part (Rowell, Jeerakan et al. 1992), and being a minor pest in Malaysia (Loke, Lim et al. 1992) and in the vegetation areas of Indonesia (Shepard and Barrion 1998). However, the study of male moth of *S. litura* occurrence in Southeast Asia reported the increasing trend of the *S. litura* toward the Northern latitudes in this region (Tojo, Mishima et al. 2008).

2.2.5 Other minor pests

The different or similar of the major lepidopteran pest species in each locality and country in Southeast Asia region are affected by their host-plant interactions and distribution. Example of others species of the minor pests reported on the *Brassica* cultivation areas are as follow: *Thysanoplusia ni* (Lepidoptera: Noctuidae), *Pontia daplidice* (Lepidoptera: Pieridae) and *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Thailand (Rowell, Jeerakan et al. 1992). *Crocidolomia pavonana* (Lepidoptera: Pyralidae), *Spodoptera exigua* (Lepidoptera: Noctuidae) and *H. armigera* in Indonesia (Shepard and Barrion 1998). *C. binotalis* and *Agrotis ypsilon* (Lepidoptera: Noctuidae) as a moderately important pests (Loke, Lim et al. 1992) (Table 2-2).

Table 2-2 Lepidopteran pests recorded from *Brassica* cultivation areas in the Southeast Asia

Lepidopteran pests	Countries						References
	Thailand	Malaysia	Indonesia	Philippines	Myanmar	Laos	
Fam. Ypeunomutidae							
P. xylostella	/	/	/	/	/	/	Keinmeesuke, Vattanatangum et al. (1992), Loke, Lim et al. (1992), Ooi (1992), Poelking (1992), Rowell, Jeerakan et al. (1992), Shepard and Barrion (1998), Rowell, Bunsong et al. (2005), Ale, Zalucki et al. (2011), Maung and Tun (2011), Soysouvanh (2011), Upanisakorn, Jeerapong et al. (2011), Upanisakorn, Sammawan et al. (2011)
Fam. Pieridae							
P. brassicae	/						Rowell, Jeerakan et al. (1992)
P. daplidice	/						Rowell, Jeerakan et al. (1992)
Fam. Pyralidae							
H. undalis	/	/					Loke, Lim et al. (1992), Rowell, Jeerakan et al. (1992), Sivapragasam and Chua (1997), Shepard and Barrion (1998)
C. pavonana		/	/				Loke, Lim et al. (1992), Sastrosiswojo and Setiawati (1992), Shepard and Barrion (1998)
Fam. Noctuidae							
S. litura	/	/	/				Loke, Lim et al. (1992), Poelking (1992), Rowell, Jeerakan et al. (1992)
S. exigua			/				Shepard and Barrion (1998)
H. armigera	/		/				Poelking (1992), Rowell, Jeerakan et al. (1992), Shepard and Barrion (1998)
T. ni	/						Poelking (1992), Rowell, Jeerakan et al. (1992)
A. ypsilon		/					Loke, Lim et al. (1992)

2.3 Parasitoids

In field condition, there are two concepts of host and parasitoid interaction as defined by Hassell and Waage (1984); namely, the density of host population affected by the level of the parasitoids parasitism, and the long term interaction between host and parasitoid was related to the degree of their stabilities. For the major lepidopteran pests of *Brassica* crops, many species of parasitic wasps and flies reported as their natural enemies (Ranga Rao, Wightman et al. 1993, Shepard and Barrion 1998, Sarfraz, Keddie et al. 2005).

2.3.1 Parasitoids of *P. xylostella*

During the development of *P. xylostella*, there are three important parasitoids; egg, larval and pupal parasitoids. In Southeast Asia, the egg parasitoids, *Trichogrammatoidea bactrae* and *Trichogramma confusum* (Hymenoptera: Chalcidoidea) were reported in the Central and Northeastern regions of Thailand, respectively (Keinmeesuke, Vattanatangum et al. 1992, Rowell, Jeerakan et al. 1992, Upanisakorn, Jeerapong et al. 2011). Sarfraz, Keddie et al. (2005) reported four important genera of the larval parasitoids of *P. xylostella*; *Cotesia* spp. (Microgastrinae), *Diadegma* spp. (Campopleginae), *Microplitis* spp. (Microgastrinae) and *Oomyzus* spp. (Eulophidae). *Cotesia plutellae* (Hymenoptera: Braconidae), are cosmopolitan parasitoids of *P. xylostella* (Talekar and Shelton 1993, Liu, Wang et al. 2000, Rowell, Bunsong et al. 2005, Sarfraz, Keddie et al. 2005). There are several studies on tri-trophic cascade interactions among *Brassica* crops, *P. xylostella* and *C. plutellae* (Shi, Liu et al. 2002, Schuler, Potting et al. 2003, Bae and Kim 2004, Ibrahim, Nissinen et al. 2005, Ibrahim and Kim 2006). The abundance of *P. xylostella* and *C. plutellae* is positively correlated (*r=0.77, p=0.001*) on their interactions in the studied of Sow, Diarra et al. (2013).

In Southeast Asia, *C. plutellae* are usually present during the *Brassica* cultivated seasons in Malaysia (Loke, Lim et al. 1992), the Philippines (Poelking 1992) and Thailand (Keinmeesuke, Vattanatangum et al. 1992, Rowell, Jeerakan et al. 1992, Rowell, Bunsong et al. 2005, Upanisakorn, Jeerapong et al. 2011). In Chiang Mai, Thailand, parasitism of *C. plutellae* was the highest in April 1989 with 88% successful parasitism rate (Rowell, Jeerakan et al. 1992)., Rowell, Bunsong et al. (2005) reported highest percentage of parasitism of 78% in an organic farm in November 2003.

Diadegma semiclasum (Hymenoptera: Ichneumonidae) was an important larval parasitoid of *P. xylostella* in Southeast Asia. At the lowlands and highlands of *Brassica* cultivation areas of Indonesia, *D. semiclasum* had been recorded with the successful parasitism on *P. xylostella* (Sastrosiswojo and Setiawati 1992, Shepard and Barrion 1998). *Diadegma semiclasum* was introduced from Australia to Malaysia and it has been established in the Cameron Highlands (Ooi 1979, Loke, Lim et al. 1992). For Thailand, they were also introduced and established in the Northeastern Region in 2005. The field survey was conducted during 2005 to 2010 to confirm their abilities to survive in this locality. Upanisakorn, Sammawan et al. (2011) reported the succession of *D. semiclasum* as a natural enemy to control population of *P. xylostella* in Thailand.

There is no report of the genus *Oomyzus* in Southeast Asia. However, *Oomyzus sokolowskii* (Hymenoptera: Eulophidae) was recorded to parasitize *P. xylostella* in the other regions (Talekar and Shelton 1993, Talekar 1997). *Oomyzus sokolowski* emerged from *C. plutella* cocoons and had been recorded with the competition to a *D. semiclasum* larva inside the host body (Liu, Wang et al. 2000, Sarfraz, Keddie et al. 2005). Finally, *Microplitis plutellae* (Hymenoptera: Braconidae) is reported with their successful parasitism on *P. xylostella* (Sarfraz, Keddie et al. 2005). In temperate countries, there are records with the diapauses over the winter (Putnam 1978), However, there are no report of parasitism of *M. plutellae* in Southeast Asia, while other species, such as *M. manila*, were dominant parasitoids of *Spodoptera litura* in *Brassica* crops (Rowell, Jeerakan et al. 1992, Shepard and Barrion 1998).

Diadromous collaris (Hymenoptera: Ichneumonidae) is the pupal endoparasitoid of *P. xylostella*. In Malaysia, *D. collaris* was introduced from Australia, and became highly successful in controling *P. xylostella* in the Cameron Highlands (Ooi 1979, Loke, Lim et al. 1992). Similarly to the highland of *Brassica* cultivation areas, *D. collaris* are usually observed as a parasitoid of *P. xylostella* in both Indonesia and Thailand (Rowell, Jeerakan et al. 1992, Shepard and Barrion 1998, Upanisakorn, Sammawan et al. 2011). Other parasitoids with low rate of parasitism are recorded in *Brassica* agricultural areas of Southeast Asia; including *Macromalon oreintale* (Loke, Lim et al. 1992, Rowell, Jeerakan et al. 1992, Rowell, Bunsong et al. 2005, Maung and Tun 2011, Upanisakorn, Jeerapong et al. 2011); *Brachymeria excarinata* (Hymenoptera: Chalcidoidea), *Brachymeria lasus* (Hymenoptera: Chalcidoidea) and *Isotima* sp. (Hymenoptera: Ichneumonidae) (Rowell, Jeerakan et al. 1992, Rowell, Bunsong et al. 2005) (Table 2-3).

Table 2-3 Parasitoids of *P. xylostella* in *Brassica* cultivation areas recorded from the Southeast Asia

Lepidopteran pests	Countries						References
	Thailand	Malaysia	Indonesia	Philippines	Myanmar	Laos	
Egg parasitoids							
T. bactrae	/						Keinmeesuke, Vattanatangum et al. (1992), Rowell, Jeerakan et al. (1992)
T. confusum	/						Rowell, Jeerakan et al. (1992)
Larval parasitoids							
C. plutellae	/	/	/	/	/		Ooi (1979), Keinmeesuke, Vattanatangum et al. (1992), Loke, Lim et al. (1992), Poelking (1992), Rowell, Jeerakan et al. (1992), Rowell, Bunsong et al. (2005), Maung and Tun (2011), Upanisakorn, Jeerapong et al. (2011)
D. semiclasum	/	/	/	/			Ooi (1979), Loke, Lim et al. (1992), Poelking (1992), Shepard and Barrion (1998), Upanisakorn, Jeerapong et al. (2011)
Larval-pupal parasitoids							
M. oreintale	/				/		Loke, Lim et al. (1992), Rowell, Jeerakan et al. (1992), Rowell, Bunsong et al. (2005), Maung and Tun (2011), Upanisakorn, Jeerapong et al. (2011)
B. excarinata	/						Rowell, Jeerakan et al. (1992), Rowell, Bunsong et al. (2005)
Pupal parasitoids							
D. collaris	/	/	/		/		Ooi (1979), Loke, Lim et al. (1992), Rowell, Jeerakan et al. (1992), Shepard and Barrion (1998), Rowell, Bunsong et al. (2005), Maung and Tun (2011), Upanisakorn, Jeerapong et al. (2011)
B. lasus	/						Rowell, Bunsong et al. (2005)
Isotima sp.	/						Rowell, Jeerakan et al. (1992), Rowell, Bunsong et al. (2005)

2.3.2 Parasitoids of *Spodoptera litura*

The revision of world natural enemies of *S. litura* by Ranga Rao, Wightman et al. (1993) reported 71 species of parasitoids which were classified into 7 families of which, 5 families were in the order Hymenoptera (Ichneumonidae, Bracobidae, Chalcididae, Trichogrammatidae, Scelionidae, Encytidae and Eulophidae) and 2 families were in the order Diptera (Tachinidae and Sarcophagidae). The genus *Microplitis* spp. had been reported with many important parasitoids species on *S. litura*. *Microplitis manilae* (Hymenoptera: Braconidae) had been reported as a primary parasitoid of *S. litura* in Chiang Mai, Thailand (Rowell, Jeerakan et al. 1992). *Microplitis manila* was introduced from Thailand to control *Spodoptera exigua* in the vegetation areas in Malaysia and *Spodoptera frugiperda* in USA, respectively (Yahaya and Sivapragasam , Rajapakse, Ashley et al. 1985). The hyperparasitism is reported on *Microplitis* sp. hosts with unidentified ichneumonid wasp (could be Mesochorinae) (Rao, Wightman et al. 1989, Rowell, Jeerakan et al. 1992, Shi, Liu et al. 2002) (Table 2-4).

Table 2-4 Parasitoids of *S. litura* in *Brassica* cultivation areas recorded from the Southeast Asia

Lepidopteran pests	Countries						References
	Thailand	Malaysia	Indonesia	Philippines	Myanmar	Laos	
Microplitis manilae	/	/					Rajapakse, Ashley et al. (1985), Rowell, Jeerakan et al. (1992)
Mesochorinae wasp	/						Rowell, Jeerakan et al. (1992)

2.3.3 Lepidopteran pests, their associated parasitoids and the interactions between lepidopteran pests - parasitoids

To understand the interaction between lepidopteran pests and their associated parasitoids, the study of parasitism is required to confirm their relationships. Rearing and dissecting techniques are the common techniques for detecting parasitism (Day 1994). Dissecting caterpillar method, gives more quantitative results of parasitism, without effect of host-plant resource, diseases (microbial infected), and stress during rearing method (Day 1994, Trang and Chaudhari 2002, Farrar, Shapiro et al. 2007, Xu, Zou et al. 2011). For rearing technique, field collected larvae and pupae of lepidopteran pests are usually separated individually in the plastic container, so that it is easy to observe, maintain and reduced the effect of cannibalism behaviour in some caterpillar species (Chapman, Williams et al. 1999, Chapman, Williams et al. 2000). Hassell and Waage (1984) reported the effect of host plant to the oviposition, development, molarity and fecundity of phytophagous pests. Food source used to feed the caterpillar in the container (mostly are organic or non-treated plants), are greatly affected both lepidopteran pests, and their associated parasitoids development (Kahuthia-Gathu, Löhr et al. 2008, Kahuthia-Gathu, Löhr et al. 2008).

2.4 Diversity of parasitic wasps

2.4.1 Parasitic wasp sampling methods

In terrestrial ecosystems, a great diversity of insects and other arthropods is driven by the diversity of their food sources and microhabitats. Grootaert, Pollet et al. (2010) proposed three categories for insect sampling methods, as follows:

I. Discontinuous or occasional and continuous sampling techniques
II. Attraction and interception sampling techniques
III. Active and passive sampling techniques

According to the definition of attractant and active-passive traps by Grootaert, Pollet et al. (2010), Yi, Jinchao et al. (2012), proposed 13 terrestrial insect traps, divided into three categories 1) passive methods without activity density bias, 2) passive methods with activity density bias and 3) active sampling methods (Table 2-5).

Table 2-5 Terrestrial insect sampling techniques proposed by Grootaert, Pollet et al. (2010) and Yi, Jinchao et al. (2012)

	Grootaert, Pollet et al. (2010)	
Active methods	Passive methods	
aspirator	colored pan trap	
portable suction device	emergence trap	
sweep net	light trap	
visual observation	Malaise trap	
	sticky trap	
	suction trap	
	Yi, Jinchao et al. (2012)	
Active methods	Passive methods with activity density bias	Passive methods without activity density bias
light trap	pitfall trap	Berlese-Tullgen funnel
pan trap	sticky trap	leaf litter collection
bait trap	suction trap	netting
pheromone trap	Malaise trap	canopy fogging
	window trap	

The hymenopterans, especially the parasitoids, are normally collected by sweep net, white and yellow pan traps, emergence traps, light traps and Malaise traps (Grootaert, Pollet et al. 2010). Noyes (1989) studied the diversity of parasitoids in tropical rain forest of Indonesia, and reported that Malaise trap, yellow pan trap and sweep net were highly effective sampling methods for collecting parasitoids, especially in the families Ichneumonidae, Braconidae, Encytidae, Eulophidae and etc.

2.4.1.1 Malaise trap

The trap named after a Swedish entomologist, who designed and promoted a new terrestrial insect trap in 1937 (Malaise 1937, Gressitt and Gressitt 1962) and was revised by Van Achterberg (2009). A black and white woven tent is a suitable trap to collect diverse diurnal flying parasitic wasps and other flying insects, such as flies (Marshall 1994, Grootaert, Pollet et al. 2010, Yi, Jinchao et al. 2012). Malaise traps had been conducted in both temperate and tropical regions, many species of parasitoids were collected by this trap, especially wasps in the families Ichneumonidae and Braconidae (Noyes 1989, Idris, Zaneedarwaty et al. 2001, Fraser, Dytham et al. 2008, Grootaert, Pollet et al. 2010, Yi, Jinchao et al. 2012).

2.4.1.2 Light trap

Light sources can attract several nocturnal insects, especially moths, some beetles and parasitoids. However, the effectiveness of the light trap depended on the type of light source with specific wave length visible to insects (Nabli, Bailey et al. 1999, Ramamurthy, Akhtar et al. 2010). Braconid parasitoids, are usually found at the light trap with highly diverse and abundance (Huddleston T and I 1988, López-Martínez, Saavedra-Aguilar et al. 2009).

2.4.1.3 Yellow pan trap

The coloured trap, especially the yellow pan trap, is normally used to sampling diurnal insect abundance. Series of flatted plastic pans filled with water and detergent could collect parasitic wasps in families Ichneumonidae and Braconidae (Noyes 1989, Grootaert, Pollet et al. 2010, Yi, Jinchao et al. 2012), with a high number of parasitoids in both lowland and highland of terrestrial ecosystems (Nelly, Rusli et al. 2010, Yaherwandi 2012, Yaherwandi and Hidrayani 2014).

2.4.1.4 Netting

Sweeping was one of the active sampling method that can collect many species of parasitic wasps. Many reports used the sweep net method to collect parasitic wasps in *Brassica* agricultural areas, lowlands and highlands of tropical rain forests of Southeast Asia. Many species of parasitoids, especially in the families Ichneumonidae and Braconidae, have been collected (Noyes 1989, Idris, Zaneedarwaty et al. 2001, Nelly, Rusli et al. 2010, Yaherwandi 2012).

2.4.2 Diversity of parasitic wasps in *Brassica* cultivation area

The study of hymenopteran parasitoids diversity in Brassicaceae plants at West Sumatra, Indonesia, reported 17 families of the parasitoids; Bethylidae, Braconidae, Chalcididae, Cerephronidae, Diapriidae, Encytidae, Eulocilidae, Eupelmidae, Ichneumonidae, Megaspilidae, Mutillidae, Mymaromatidae, Platigastridae, Pteromalidae, Scelionidae, Torymidae and Trichogrammatoidae. Diversity and abundance of these parasitoids were different between the simple and complex landscapes and between Brassicaceae and other crops cultivation areas (Yaherwandi 2012). Whereas, the diversity of the parasitoids of the lepidopteran hosts were reported with difference diversity and abundance among several Brassicaceae plant species (Nelly, Rusli et al. 2010).

2.5 Relationships of *Brassica* plants, lepidopteran pests and their parasitoids

Several studies described the interactions between plants, pests and parasitoids. Most of the relationships have been reported at the scale of species-species interactions, such as chemical compound of plant and phytophagous pest interactions, pest and parasitoid specificity and the cascade effect on plant, pest and parasitoid food webs (Vinson 1976, Vinson and Iwantsch 1980, Vinson and Iwantsch 1980, Hassell and Waage 1984, Hassell 2000). Many studies on plants, pests and parasitoids driven by effect of the diversification have also been published. Shaw (2006) reported the important impact of landscape arrangement to pests and parasitoid interactions, with the top down effect. The diversity of plantations decreased the abundance of phytophagous pests but increased the abundance of parasitoids (Letourneau 1997). Landis, Menalled et al. (2005) reported a complex landscape had a higher diversity of parasitic wasps than a simple landscape, in collard (*Brassica oleracae*) fields where the predators and parasitoids were highly diverse in the complex landscape (Richard 1973). Parasitoids spent more time during host searching behaviour in a simple landscape (Andow and Prokrym 1990), and the parasitism rates were higher in the simple landscape during the beginning of plant cultivation. However, in long-term effect, the parasitism rates were high in the complex landscape (Landis, Menalled et al. 2005). For the pest development, the mortality rates, natural enemies diversity and parasitism in the complex landscape were higher than the simple landscape (Russell 1989, Marino and Landis 1996). Lastly, Hole, Perkins et al. (2005) reported that growth rate of aphid was faster in a conventional agriculture landscape (chemical insecticides and fertilizers used) than an organic agriculture landscape, while the abundance of parasitic wasps in the organic landscape was higher than the conventional landscape (Hole, Perkins et al. 2005).

The relationships among *Brassica* crops, lepidopteran pests, beneficial parasitoids and climatic factors had been studied in two scenario models. First, the relationships of plants, pests and beneficial parasitoids species (Sow, Diarra et al. 2013), and plants, pests and beneficial parasitoids families/subfamilies (Bothwell 2012). Sow, Diarra et al. (2013) reported significant correlation among climatic factors, age of *Brassica* plants and the lepidopteran pest, *P. xylostella*. The climatic factors lead to the fluctuation of the abundance of pests and parasitoids. *Plutella xylostella* abundance was significantly related to the parasitoid density (*Oomyzus sokolowskii*, *Apanteles litae* and *Cotesia plutellae*), and the pest population abundance related to the parasitism rate. Bothwell (2012) studied the landscape effect to the ichneumonid wasps diversity and parasitism and found the same results as Sow, Diarra et al. (2013) but the experiments had been conducted in both host-parasitoid rearing technique and trap samplings. Malaise traps are used to monitor diversity of beneficial parasitic wasps. *Thychoplusia ni* was the dominant pests on the vegetation areas in the studied of Sow, Diarra et al. (2013). *Hyposoter exiguae* was one of their associated parasitoids, their abundance recorded from the host rearing were positively correlated to the abundance of Campopleginae in the Malaise traps.

CHAPTER 3
MATERIALS AND METHODS

3.1 Study sites

The study sites were located at Moo 1, Bann Lainan, Lainan Subdistrict, Wiang Sa District, Nan Province (Figure 3-1 A, B). Three *Brassica* cultivation sites; Lainan I (LN1), Lainan II (LN2) and Lainan III (LN3) (Table 3-1), approximately 185 – 190 m above mean sea level and usually flooded during the monsoon months (July – August). The study sites were approximately 200 – 500 m apart and separated by other *Brassica* farms, other vegetable farms and fruit orchards (Figure 3-2).

The sizes of three study sites are were 0.32, 0.24 and 0.08 Ha in LN1, LN2 and LN3, respectively, while the total vegetable cultivation area was approximately 120 Ha in Wiang Sa District, Nan Province (Table 3-1). The first site, LN1 (Figure 3-3 A, B) is at the south part of Baan Lainan Village, while LN2 (Figure 3-3 C, D) is at the centre and LN3 (Figure 3-3 E, F) was located at the south of the village.

Table 3-1 Study site locations and area (Ha) at Moo 1, Baan Lainan, Lainan Subdistrict, Wiang Sa District, Nan Province

Sites	Area (Ha)	Location (degree)	Longitude (degree)
LN1	0.32	18° 57' 42.38" N	100° 75' 93.47" E
LN2	0.24	18° 57' 60.05" N	100° 75' 90.82" E
LN3	0.08	18° 57' 87.00" N	100° 75' 70.65" E

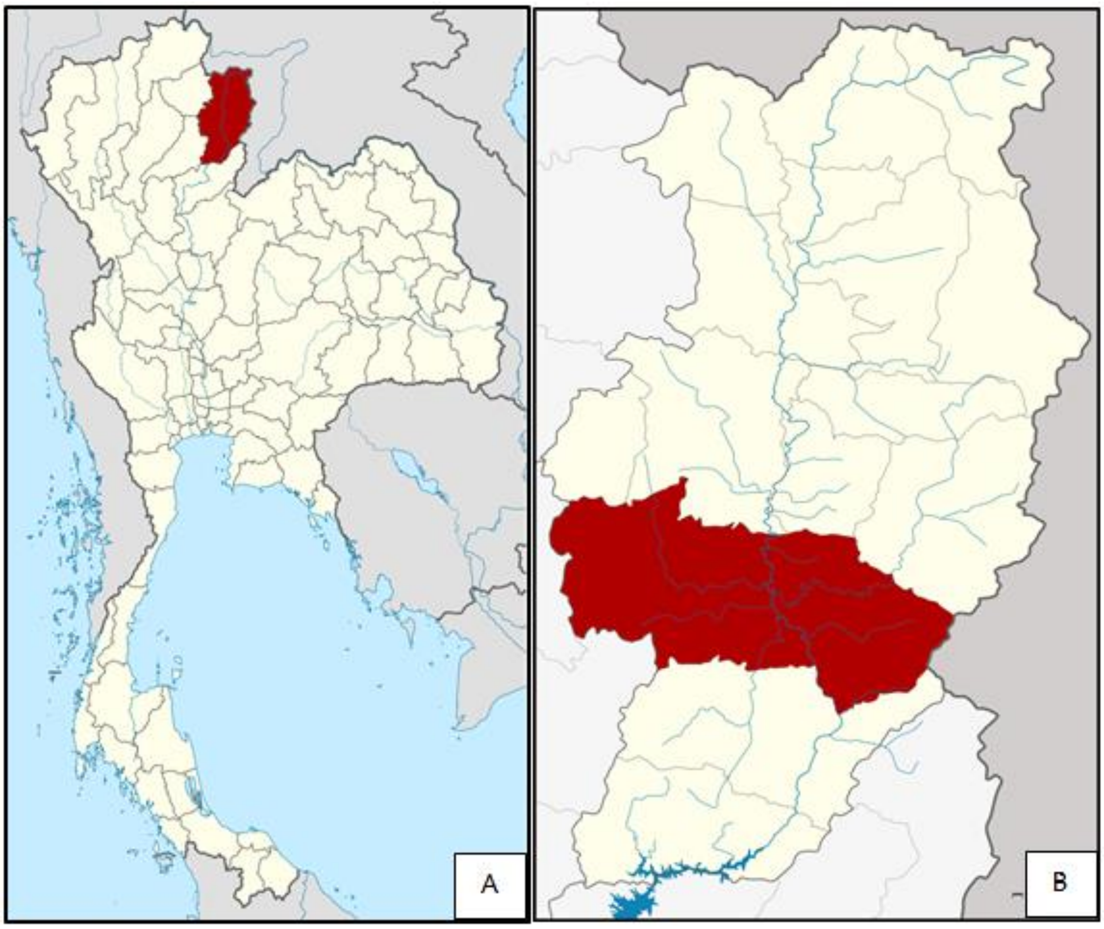

Figure 3-1 Map of the study areas; A, map of Thailand shows where Nan Province is located (red); B, map of Nan Province, Wiang Sa District is located on the red area (http://en.wikipedia.org/wiki/Nan_Province#mediaviewer/File:Thailand_Nan_locator_map.svg) (http://en.wikipedia.org/wiki/Wiang_Sa_District,_Nan#mediaviewer/File:Amphoe_5507.svg)

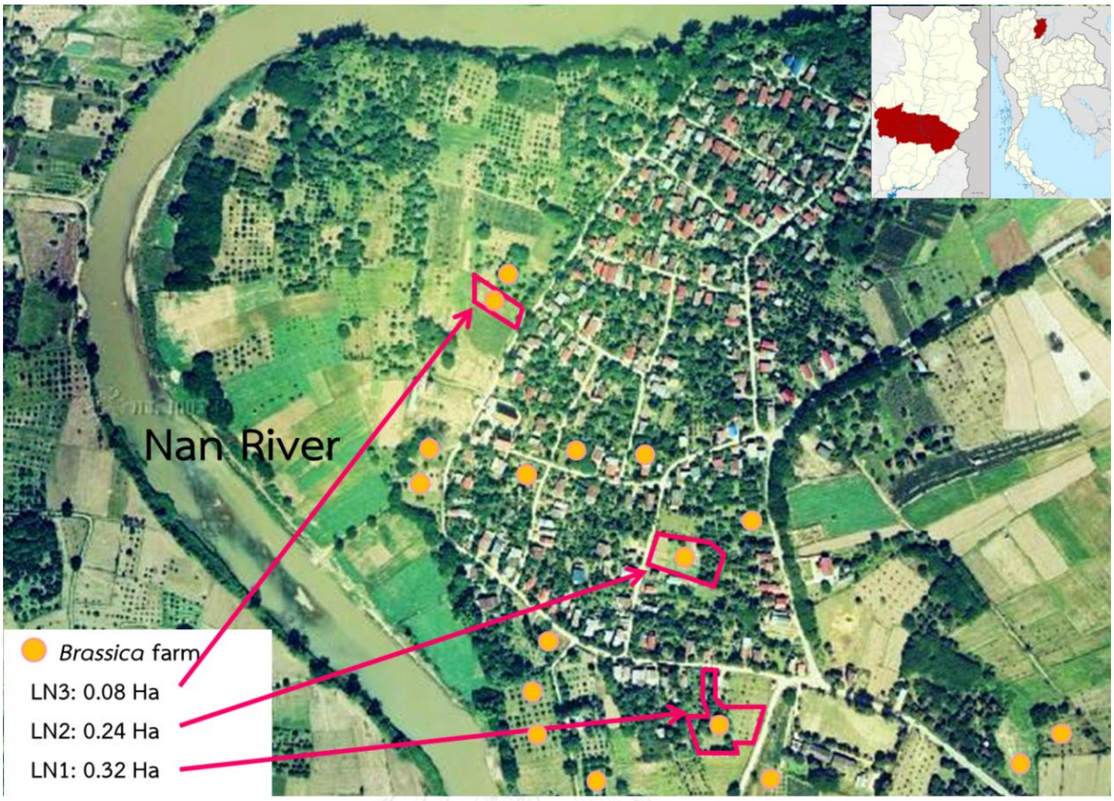

Figure 3-2 Location of the study areas; LN1, LN2, LN3 and other *Brassica* farms at Lainan Subdistrict, Wiang Sa District, Nan Province (Aerail photograph taken by the Department of Land Development in 2002)

Figure 3-3 *Brassica* cultivation areas at Baan Lainan, Moo 1, Lainan Subdistrict, Wiang Sa District, Nan Province: A, December 2012 and B, March 2013: LN1 site; C, December 2012 and D, January 2013: LN2 site; E, November 2012 and F, November 2012: LN3 site

3.2 Cultivation practice

The *Brassica* cultivation areas at Lainan Subdistrict are geographically and climatically suitable for growing most of the *Brassica* cultivars. Each year, *Brassica* cultivated season normally started a few weeks after annual flooding in August – September and ended in March next year. Five cultivars of *Brassica* crops had been recorded from all of the study sites; cabbage (*Brassica oleracea* L. var. *capitata* L.) (Figure 3-4 A), broccoli (*B. oleracea* L. var. *italic*) (Figure 3-4 B), cauliflower (*B. oleracea* L. var. *botrytis* L.) (Figure 3-4 C), Chinese kale (*B. oleracea* L. var. *alboglabr*a Bailey) (Figure 3-4 D), and pak choi (*B. chinensis* Jusl var. *parachinensis* (Bailey) Tsen & Lee) (Figure 3-4 E) (NDOA 2010, NDOA 2011). There were similar to the other parts of *Brassica* farm in Nan Province. The growth stages (seeding – harvesting stages) of each *Brassica* cultivar are different, therefore during one cultivation season, farmers can grow 2–4 cycles of crops depending on *Brassica* cultivar. Apart from *Brassica*, other crops were grown either mixed or rotated during and between *Brassica* cultivated seasons in all of the study sites, such as morning glory, eggplant, gourd, corn, pumpkin and etc. (Table 3-2).

Figure 3-4 A, cabbage (*Brassica oleracea* L. var. *capitata* L.); B, broccoli (*B. oleracea* L. var. *italic*); C, cauliflower (*B. oleracea* L. var. *botrytis* L.); D, Chinese kale (*B. oleracea* L. var. *alboglabra* Bailey); E, pak choi (*B. chinensis* Jusl var. *parachinensis* (Bailey) Tsen & Lee)

Table 3-2 Planting schedule at each study site during and between *Brassica* cultivated seasons (BCS) (October 2012 – November 2013)

Plans	Site	During BCS						Between BCS					During BCS		
		Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
Cabbage	LN1	■	■	■	■	■	■	■							■
	LN2	■	■	■	■	■	■	■					■	■	■
	LN3	■	■	■	■	■									■
Broccoli	LN1	■	■	■	■	■	■	■					■	■	■
	LN2	■	■	■	■	■	■	■					■	■	■
	LN3	■	■	■	■	■									■
Cauliflower	LN1	■	■	■	■	■	■	■					■	■	■
	LN2	■	■	■	■	■	■						■	■	■
	LN3	■	■	■	■	■									■
Chinese kale	LN1	■	■	■									■	■	
	LN2	■	■	■	■					■	■			■	■
	LN3			■											■
Pak choi	LN1	■	■	■											
	LN2	■	■	■	■						■		■	■	
	LN3		■	■	■	■									
Morning glory	LN1	▒		▒	▒	▒		▒	▒	▒		▒	▒	▒	▒
	LN2	▒	▒	▒	▒	▒		▒	▒	▒	▒	▒	▒	▒	▒
	LN3		▒	▒	▒	▒				▒	▒				▒
Small eggplant	LN1							▒	▒		▒				
	LN2												▒		
	LN3						▒	▒	▒		▒				
Guard	LN1						▒	▒	▒	▒	▒				
	LN2					▒	▒	▒	▒	▒	▒				
	LN3										▒				
Corn	LN1														
	LN2														
	LN3	▒	▒												
Pumpkin	LN1														
	LN2														
	LN3	▒	▒	▒											
Chinese celery	LN1					▒									
	LN2				▒	▒									
	LN3														
Ceylon spinach	LN1	▒						▒	▒	▒					
	LN2	▒	▒					▒	▒	▒					▒
	LN3														
Dill	LN1														
	LN2				▒										▒
	LN3														
Cucumber	LN1										▒				
	LN2														
	LN3														

■ = *Brassica* crops ▒ = Other vegetables

3.3 Field management

In this study sites, several mwthods have been combined to control pest population. For cultural control, the *Brassica* cultivation sites were surrounded with the meshed fence to control pest and animal disturbance (Figure 3-5 A). Agricultural plots were prepared by tillage and solarization to eliminate weeds, eggs and juveniles of the pests (Figure 3-5 B). *Brassica* spp. was seeded on plots for two weeks, and then seedlings were transplanted to the growing plots with the space between rows and columns of each plant to increase developmental efficiently, maintenance and reduced spreading of the pests (Figure 3-6 A, B). Chemical fertilizer (urea) had been applied during and between *Brassica* cultivated seasons in all study sites. Pesticides used in each study site were different. In LN1, a herbicide (Grammoxone: Paraquat dichloride) was applied between the *Brassica* seasons (April 2013) on weeds for gourd plot preparation. Also, during the start of 2013–2014 *Brassica* cultivated season, a molluscicide (Deadmeal-5: Metaldehyde) was applied on LN1. An insecticide (Mozat: Abamectin) was applied in October 2013 after reaching economic threshold of *Spodoptera litura* caterpillars in LN1. A fungicide (Acmeguard) was used in November 2013 to control microbial infection at LN2. Although, LN3 had no record of any chemical application, it might receive the pesticides from the neighbour’s pomelo orchard (20 m away) which applied pesticide regularly (Table 3-3, 3-4, 3-5).

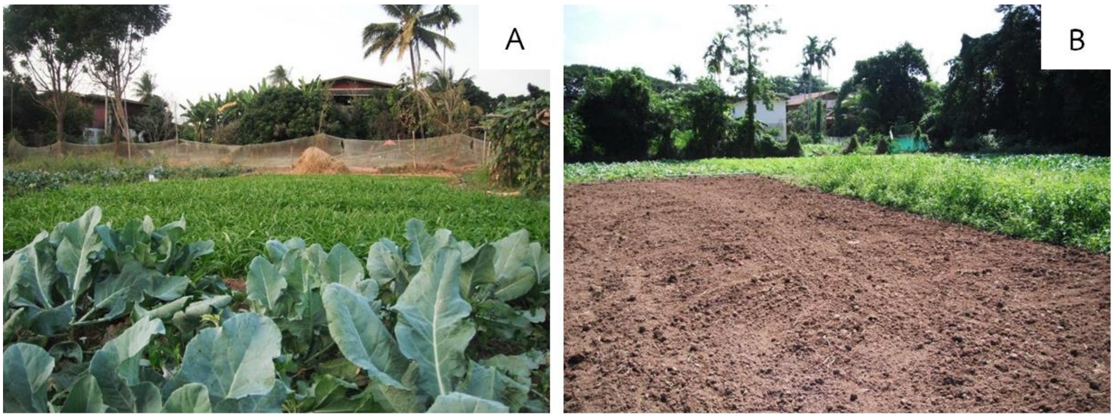

Figure 3-5 Cultural controls; A, mesh net; B, dry soil for plot preparation

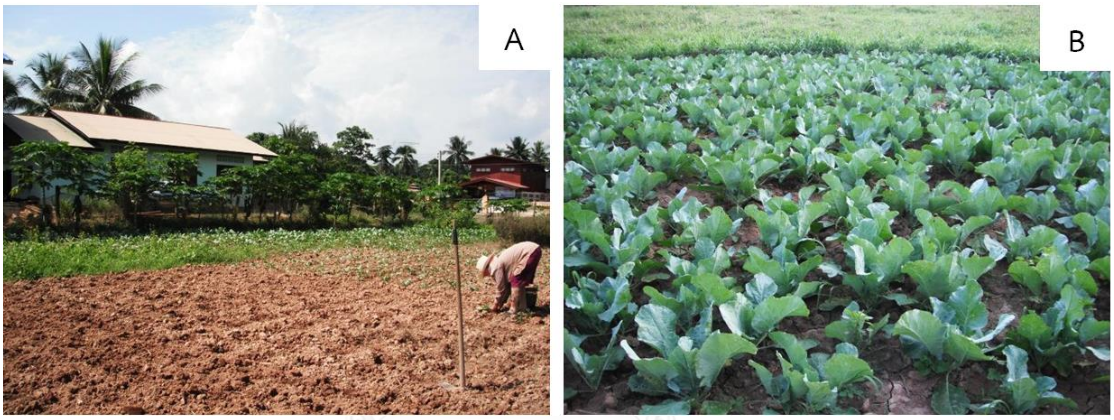

Figure 3-6 A, Transplanting of two weeks old *Brassica* spp.; B, the growing plot with space between row and column of the plants

Table 3-3 *Brassica* crops cultivation and field management at LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Cabbage	Broccoli	Cualiflower	Chinese kale	Pak choi	No. of *Brassica* cultivars	Size of Brassica cultivation areas (m^2)	Flooded	Molluscicide	Insecticide	Herbicide	Fungicide
Oct-12	/	/	/	/	/	5	1600					
Nov-12	/	/	/	/	/	5	3200					
Dec-12	/	/	/	/	/	5	640					
Jan-13	/	/	/			3	1280					
Feb-13	/	/	/			3	640					
Mar-13	/	/	/			3	640					
Apr-13	/	/	/			3	320				/	
May-13						0	0					
Jun-13						0	0					
Jul-13						0	0					
Aug-13						0	0		/			
Sep-13		/	/	/		3	1920					
Oct-13		/	/	/		3	2240			/		
Nov-13	/	/	/			3	960					

Table 3-4 *Brassica* crops cultivation and field management at LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Cabbage	Broccoli	Cualiflower	Chinese kale	Pak choi	No. of *Brassica* cultivars	Size of Brassica cultivation areas (m^2)	Flooded	Molluscicide	Insecticide	Herbicide	Fungicide
Oct-12	/	/	/	/	/	5	1200					
Nov-12	/	/	/	/	/	5	1920					
Dec-12	/	/	/	/	/	5	1440					
Jan-13	/	/	/	/	/	5	960					
Feb-13	/	/	/			3	480					
Mar-13	/	/	/			3	720					
Apr-13	/	/				2	240					
May-13						0	0					
Jun-13				/		1	120					
Jul-13				/	/	2	120					
Aug-13						0	0					
Sep-13	/	/	/		/	4	960					
Oct-13	/	/	/	/	/	5	1920					
Nov-13	/	/	/	/		4	1680					/

Table 3-5 *Brassica* crops cultation and filed management at LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Cabbage	Broccoli	Cualiflower	Chinese kale	Pak choi	No. of *Brassica* cultivars	Size of Brassica cultivation areas (m^2)	Flooded	Molluscicide	Insecticide	Herbicide	Fungicide
Oct-12	/	/	/			3	480					
Nov-12	/	/	/		/	4	480					
Dec-12	/	/	/	/	/	5	480					
Jan-13	/	/	/		/	4	320					
Feb-13	/	/	/		/	4	320					
Mar-13						0	0					
Apr-13						0	0					
May-13						0	0					
Jun-13						0	0					
Jul-13						0	0					
Aug-13						0	0	/				
Sep-13						0	0					
Oct-13						0	0					
Nov-13	/	/	/	/		4	320					

3.4 Physical factors

Air temperature (°C) and air humidity (%) were recorded using digital hygro-thermometer during the field observation time (8.00 – 11.00 A.M.), then averaged each month from the three study sites. The monthly values were compared with the temperature, humidity wind speed and rainfall recorded by the Thai Meteorological Department (Nan Provincial Agricultural Extension Office Station).

3.5 Relationships among *Brassica* crops, lepidopteran pests and parasitoids

Three-trophic relationships among *Brassica* crops, lepidopteran pests and their associated parasitoids were observed during nine months of *Brassica* cultivated seasons (October 2012 – March 2013 and September - November, 2013). Data of *Brassica* cultivars, lepidopteran pests and parasitoids were evaluated statistically for their interactions, abundance and diversity from the study sites.

3.5.1 *Brassica* crops

Brassica cultivars and other vegetables grown at LN1, LN2 and LN3 were recorded during October 2012 – November 2013. The cultivars and area of *Brassica* cultivation sites were recorded each month because biological factors could be related to the lepidopteran pests and beneficial parasitoids during and between *Brassica* cultivated seasons.

3.5.2 Lepidopteran pest collection

Larvae and pupae of the lepidopteran pests were randomly collected from approximately 20 percent of the total *Brassica* plots in each study site. Observation on lepidopteran pests was done every month during *Brassica* cultivated seasons (October 2012 – March 2013 and September – November 2013). The lepidopteran pests collection was conducted during 8.00 – 11.00 A.M. for two days consecuatively, The pests were located by spotting the damaged plant; leaf pores (Figure 3-7 and 3-8 A), the muck on stems and leaves. Leaves were flipped to check for larvae on both sides (top and bottom) (Figure 3-7). The pupae of lepidopteran pests (Figure 3-8 B) were located by their larval exuviae on the plant. The collected larvae and pupae were placed in a bright plastic bag, separated by host plant species and a label was placed in the bag with the locality, date of collection and host plant species (Figure 3-9).

Figure 3-7 Cluster of the cotton leafworms (*S. litura*) on the bottom of broccoli leaf

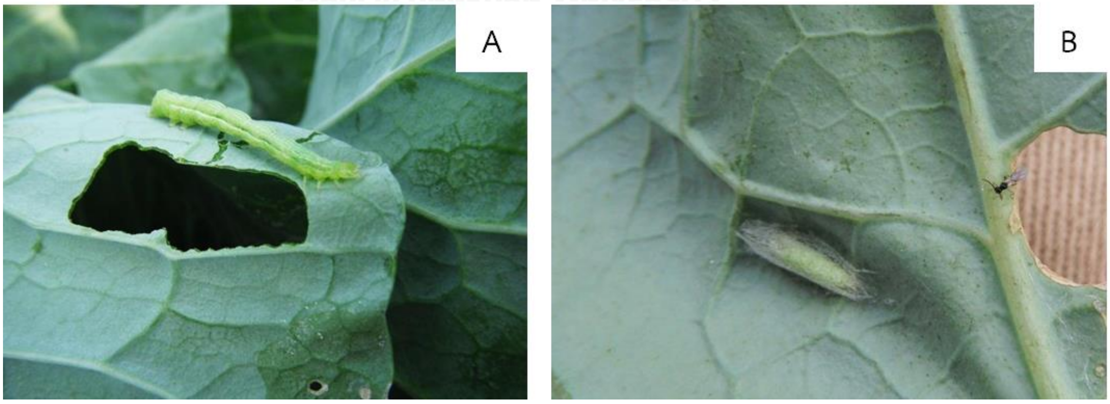

Figure 3-8 A, larva of cabbage looper on the damaged leaf; B, the pupa of diamondback moth under the Chinese kale leaf

Figure 3-9 The larvae of lepidopteran pests in a plastic bag prepared for the host rearing process

3.5.3 Host and parasitoid rearing

Larvae and pupae of the lepidopteran pests were reared in the laboratory at the Chulalongkorn University Forest and Research Station, Lainan Subdistrict, Wiang Sa District, Nan Province (5 kilometers away from the study sites). The lepidopteran pests were separated individually into a bright plastic cup (7 cm diameter x 5 cm height) for observation (Figure 3-10). The plastic cups were placed on the shelves at the laboratory with the room temperature varied from 15 – 35 °C (day and night), light period was set for 12:12 hr of day and night period. The shelves were covered with fine woven nets to protect the pests from natural enemies and other animal disturbance (Figure 3-11). The larvae of lepidopteran pests were given 20 g of fresh green organic cabbage leaves to prevent the mortality from any residual agrochemicals (Kahuthia-Gathu, Löhr et al. 2008, Kahuthia-Gathu, Löhr et al. 2008). The plastic cups were observed daily from 18.00-22.00 for cabbage replacement and developmental observation until the larvae developed to the pupation stage. In case of parasitized larva, the cabbage was immediately removed when the parasitoid completed the pupation process.

Figure 3-10 A lepidopteran pest was reared individually in a plastic cup, for observation of potential parasitoids

Figure 3-11 The rearing shelf was covered with a woven net

3.6 Diversity and abundance of parasitic wasps

Diversity of parasitic wasps was studied during and between *Brassica* cultivated seasons (October 2012–November 2013). Four insect sampling methods had been used to collect the parasitoids; Malaise traps, mobile bucket light traps, yellow pan traps, and aerial net (Grootaert, Pollet et al. 2010, Yi, Jinchao et al. 2012) to inclusively collect flying adult parasitic wasps from the study sites.

3.6.1 Malaise trap

One Malaise trap (150 x 165 x 190 cm of width x depth x height), was set 1 trap / site at the centre of each *Brassica* study site and left in place from October 2012 - November 2013 (Figure 3-12). The collecting bottle containing 95% (v/v) ethanol, was harvested and replaced with fresh ethanol every week. The samples were dated and then sorted for only parasitic wasps.

3.6.2 Mobile bucket light trap

Two mobile bucket light traps (Figure 3-13 A, B), each comprised of a plastic bucket (12x12x15 cm) with a pair of LED black lights (20 cm) and batteries, were operated overnight for 2 consecutive nights every month (4:00 PM–8:00 AM). The samples were preserved in 95% (v/v) ethanol for subsequent identification and parasitic wasp species were counted.

3.6.3 Aerial net

Aerial net sweeping was conducted two consecutive days each month, between 8:00–11:00 AM (Figure 3-14 A). A net was swept randomly over 180 degrees above the *Brassica* plants, five times then the caught insects were transferred to 95% (v/v) ethanol for subsequent taxonomic identification and counting.

3.6.4 Yellow pan trap

Four yellow pan traps (20 cm diameter x 7 cm height of yellow plastic bowls, filled with 5% detergent solution) were placed at each study site between 8:00 AM–4:00 PM, two consecutive days per month (Figure 3-14 B). The collected insects were then examined and only parasitic wasps were transferred into 95% (v/v) ethanol for subsequent identification.

Figure 3-12 The Malaise traps were set at LN1, LN2 and LN3 sites

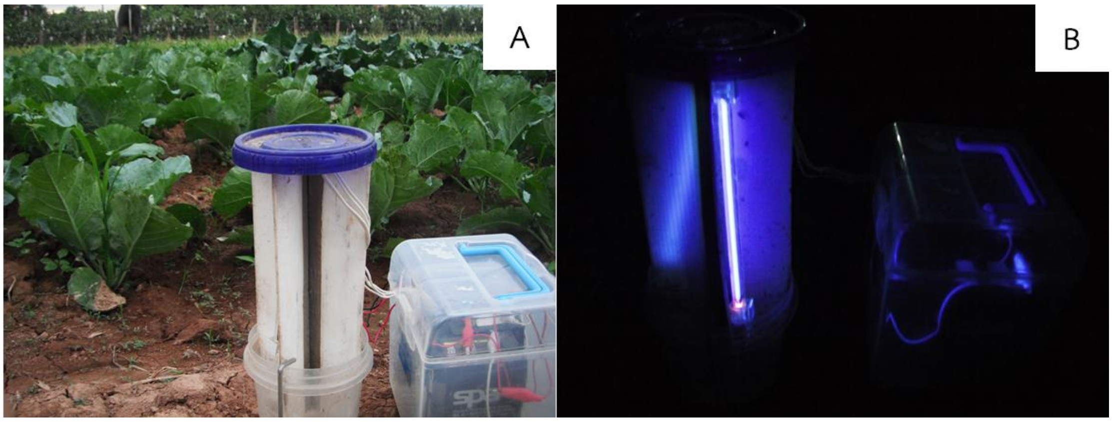

Figure 3-13 A, Mobile bucket light trap operated at the *Brassica* agricultural area; B, LED black light at night

Figure 3-14 A, Aerial net used to collect adult parasitic wasps; B, yellow pan trap filled with 5% detergent solution on *Brassica* cultivation area

3.7 Taxonomic processing

3.7.1 Lepidopteran pest identification

Lepidopteran pest larvae were identified using the guide book of Ek-amnuay (2010), while the adult lepidopteran pests were killed using ethyl acetate solution, setting, pinning and identified followed to (Lewvanich 2001).

3.7.2 Parasitic wasp identification

Adult parasitoids emerged from host rearing were preserved in 95% (v/v) ethanol, and identified using the dichotomous key of Whitfield (1995) and Whitfield, Rodriguez et al. (2009). Only parasitic wasp specimens were sorted from trap samplings, and then preserved in 95% ethanol. The identification was conducted to the family/subfamily level of parasitic wasps which reported the parasitoids of lepidopteran hosts (Van Achterberg 1990, Goulet and Huber 1993, Broad 2006).

3.7.3 Photograph and specimen deposition

Adult lepidopteran pests, parasitoids from host rearing and from trap sampling were photographed with Cell^D programs at The Animal Systematics Research Unit, Faculty of Science, Chulalongkorn University. Lepidopteran pests and parasitic wasp specimens were given the voucher numbers and deposited at the Insect Museum, Museum of Natural History, Chulalongkorn University.

3.8 Statistical analysis

3.8.1 Prevalence index analysis

Frequency and abundance of Ledidopteran pests were used to calculate the prevalence index. The pests were classified into two groups: major and minor pests (followed by the mean of prevalence index), to compare their phytophagous pests' status with the previous studies. The abundance of each species was scored as rank (Table 3-3, Figure 3-15). Host rearing parasitoids and the parasitic wasps from the trap sampling were also analyzed with the same equation although with a different scale on the rank score (Table 3-4, Figure 3-16).

$$Prevalence\ index = Frequency \times Abundance$$

$$Prevalence\ index = \frac{Times\ of\ samples\ with\ insects}{Times\ of\ total\ samples} \times \frac{Sum\ of\ rank\ score}{Times\ of\ samples\ with\ insects}$$

$$Prevalence\ index = \frac{Sum\ of\ rank\ score}{Times\ of\ total\ samples}$$

Where

Frequency = the ratio between times of samples with insects (pests or parasitoids) and times of total samples

Times of samples with insects = times of each species of pest or parasitoids recorded

Times of total samples = total times sampling of pests or parasitoids (for pest and parasitoids in host rearing methods, total times observed = 9; for parasitoids in trap sampling, total times observed = 14)

Abundance = the sum of rank score of each samples species per times of samples with insects

Sum of rank score = rank score is the value that represent to the number of pest and parasitoid in each range, the range of pest and parasitoid numbers follows the Poisson's distribution (Table 3-6, Figure 3-15, Table 3-7 and Figure 3-16)

Table 3-6 Rank score of the lepidopteran pests

Number of lepidopteran pests	Rank score
1-10	1
11-40	2
41-90	3
91-180	4
180-360	5
361-720	6
More than 720	7

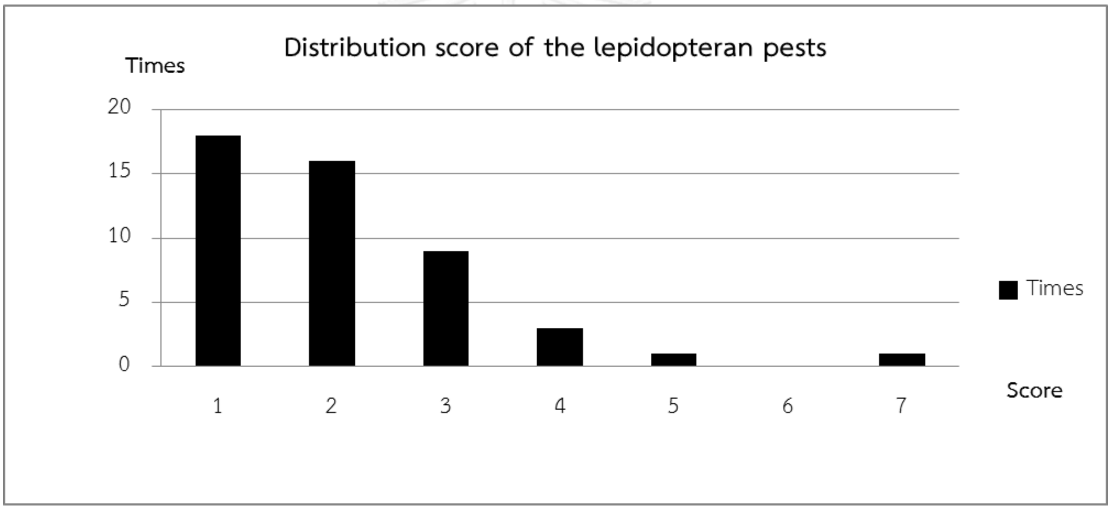

Figure 3-15 Distribution of rank score of the lepidopteran pests (Poisson's distribution)

Table 3-7 Rank score of the parasitic wasps

Number of parasitic wasps	Rank score
1-3	1
4-10	2
11-20	3
21-40	4
41-80	5
81-160	6
More than 160	7

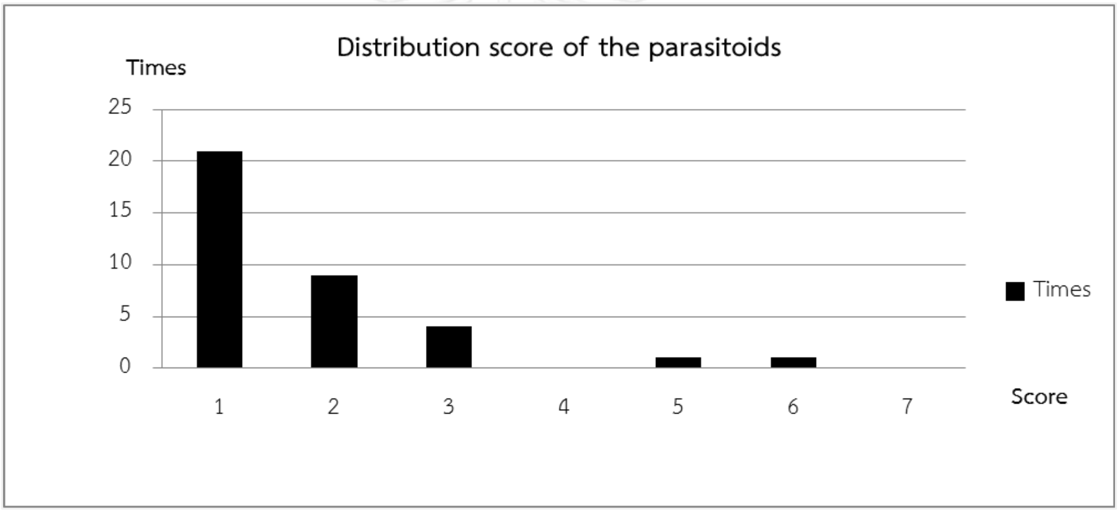

Figure 3-16 Distribution of rank score of the parasitoids (Poisson's distribution)

3.8.2 Parasitism rates of parasitoids

Parasitism rate was used to evaluate the effectiveness of the parasitoids. The emerged parasitoid species were recorded along with their lepidopteran host species. Total successful parasitism by the parasitoids was evaluated with the total number of their host. However, in case of gregarious parasitoids (more than one parasitoid emerge from one host), they were counted as one parasitism on their hosts.

$$Parasitism\ Rate = \frac{Number\ of\ successful\ developed\ parasitoids}{Total\ number\ of\ their\ lepidopteran\ hosts}$$

3.8.3 Analysis of diversity indices

The diversity index is the tool for measuring the biodiversity, such as species richness, species evenness and abundance (Magurran and McGill 2011). Simpson's Index and Shannon-Wiener Function (Krebs 1999) were calculated for the diversity measurement of lepidopteran pests, beneficial parasitoids and other parasitic wasps collected from the traps.

Simpson's Index

$$D = \sum p_i^2$$

Where

D = Simpson's index

p_i^2 = Proportion of species i in the community

Shannon-Wiener Index

$$H' = -\sum_{i=1}^{S} (p_i)(log_{10} p_i)$$

Where

H' = Information content of sample (bits/individual) index of species diversity

S = Number of species

p_i = Proportion of total sample belonging to i th species

3.8.4 Analysis of physical and biological factors among the three study sites

Comparison of the physical and biological factors have been analyzed among the three study sites using the Kruskall-Wallis Test performed with Sigmaplots v11.1.0.

3.8.5 Analysis of the physical factors, plants, lepidopteran pests and parasitic wasps interactions

Sperman Rank Order Correlation (which analyzed by Sigmaplots v11.1.0) was used to analyze the interactions of physical factors, plants, lepidopteran pests and parasitic wasps.

3.8.6 Analysis of physical and biological factors during and between *Brassica* cultivation seasons

To evaluating the effect of field managements and the plantation by the farmers to the physical and biological factors, the Sigmaplots v11.1.0 was used to compare the the physical and biological factors during and between *Brassic*a cultivated seasons.

CHAPTER 4
RESULTS

4.1 Physical factors

During October 2012 – November 2013, average monthly temperature and TMD temperature were ranged from 22.7-32.4 ℃ and 23.7-33.0 ℃, respectively. The lowest average temperature during the observation time was 22.7 ℃ in January, 2013, while the lowest TMD temperature was 23.7 ℃ in February 2013, recorded during the *Brassica* cultivated seasons, at the same period of the highest percentage of humidity, 74.8 % on December, 2012 (Figure 4-1).

Average temperature and wind speed during (October 2012 – March 2013 and September-November 2013) and between *Brassica* cultivated seasons (April-August 2013) showed significant difference (*t-test*: $t=-2.300$, $df=12$, $p=0.040$; $t=-3.283$, $df=12$, $p=0.007$, respectively), whereas average humidity was not significantly different ($t=1.666$, $df= 12$, $p=0.122$). Average field temperature among three study sites was positively correlated with the temperature recorded from Thai Meteorogical Department (TMD), Nan Provincial Agricultural Extension Office Station, TMD temperature (Spearman correlation: $r_S=0.726$, $p=0.003$).

The wind speed from TMD records was ranged from 3.0-7.7 Knots, with the highest speed in May, 2013 (between *Brassica* cultivated season). The TMD precipitation (total rainfall) was not different during and between *Brassica* cultivaed seasons (Mann-Whitney U Statistic=11.00 , $p=0.222$) The highest total rainfall was recorded in Septemper, 2013 with 281.1 mm^3. However the precipitation in study areas ranged from 5.6-281.1 mm^3 and LN3 site was flooded in August, 2013.

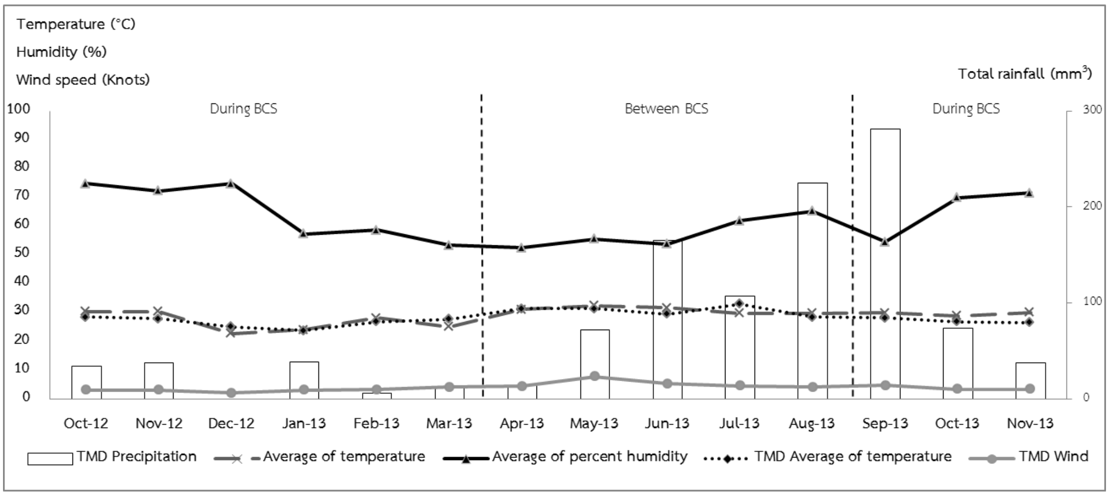

Figure 4-1 Physical factors (air temperature, humidity, wind speed and precipitation) at *Brassica* agricultural areas during and between *Brassica* cultivated seasons (BCS) (October 2012-November 2013), Lainan Subdistrict, Wiang Sa District, Nan Province

4.2 *Brassica* crops

Five cultivars of *Brassica* crops were cultivated in all of the study sites; namely, cabbage (*Brassica oleracea* L. var. *capitata* L.), broccoli (*B. oleracea* L. var. *italic*), cauliflower (*B. oleracea* L. var. *botrytis* L.), Chinese kale (*B. oleracea* L. var. *alboglabr*a Bailey), and pak choi (*B. chinensis* Jusl var. *parachinensis* (Bailey) Tsen & Lee). However, there was no significant difference among the cultivated proportions of cabbage, broccoli, cauliflower, Chinese kale, pak choi and variety of the *Brassica* crops among the three study sites. (Kruskal-Wallis: *H=2.278, df=2, P=0.320; H=3.154, df=2, p=0.207; H=2.508, df=2, p=0.285; H=5.467, df=2, p=0.065; H=2.719, df=2, p=0.257;* and *H=3.437, df=2 p=0.179*, respectively).

Although the total size of *Brassica* cultivation area were different in each study site (LN3 was significantly smaller than LN1 and LN2, Figure 4-2) (Kruskal-Wallis: *H=9.310, df=2, p=0.010*) (Figure 4-3), the percentage of *Brassica* cultivation was the same pattern of the cultivation, with the highest proportion of *Brassica* cultivation area during the seasons (Figure 4-4, 4-5 and 4-6). In addition to the species of *Brassica* cultivars planted each month, there was no significant difference among the three study sites (*H=3.437, df=2, p=0.179*) (Figure 4-7). The size of *Brassica* cultivation area was positively correlated with the humidity (Spearman correlation: r_S*=0.542,* *p=0.043*), but negatively correlated to the temperature (r_S=*-0.536, p=0.047*). Similarly, number of *Brassica* cultivars each month was positively correlated to the average humidity (r_S=*0.608, p=0.020*) but negatively correlated to the temperature (r_S=*-0.709, p=0.004*). Moreover, number of *Brassica* cultivars each month was positively correlated to *Brassica* cultivation areas (r_S=*-0.921, p<0.001*) (Figure 4-7).

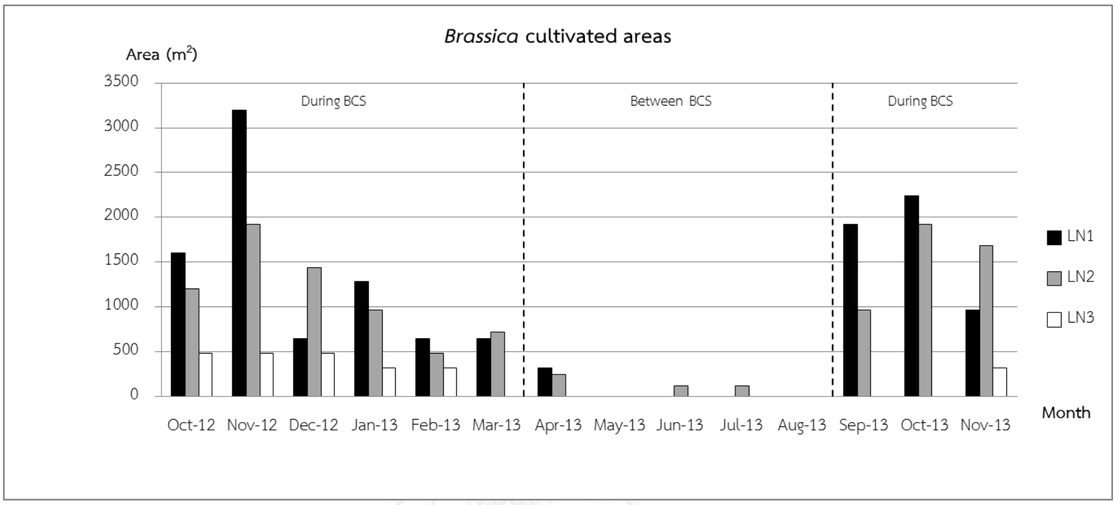

Figure 4-2 Total sizes of *Brassica* cultivated areas in the three study sites during and between *Brassica* cultivated seasons (BCS) (October 2012-November 2013)

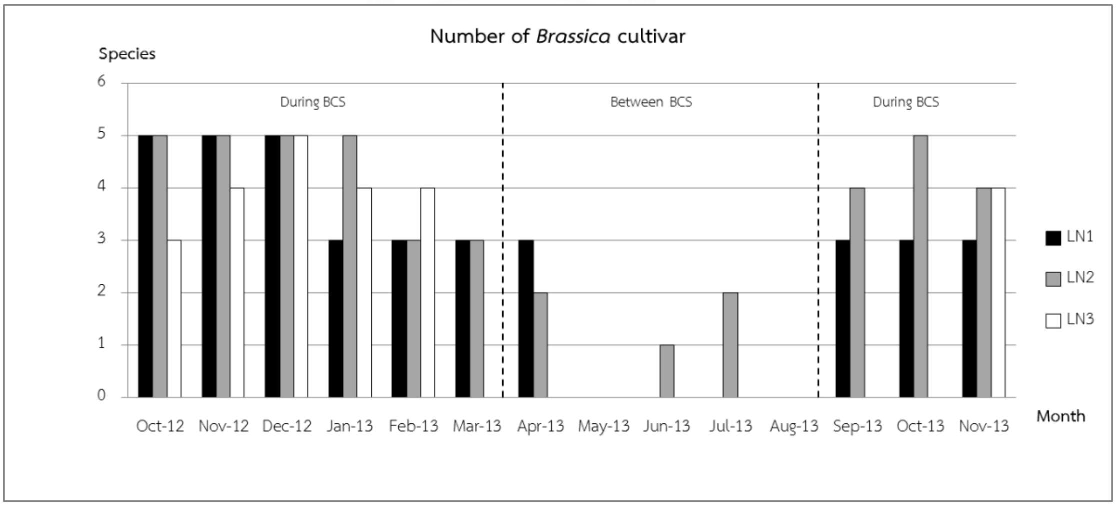

Figure 4-3 Number of *Brassica* cultivars in each month in the three study sites during and between *Brassica* cultivated seasons (BCS) (October 2012-November 2013)

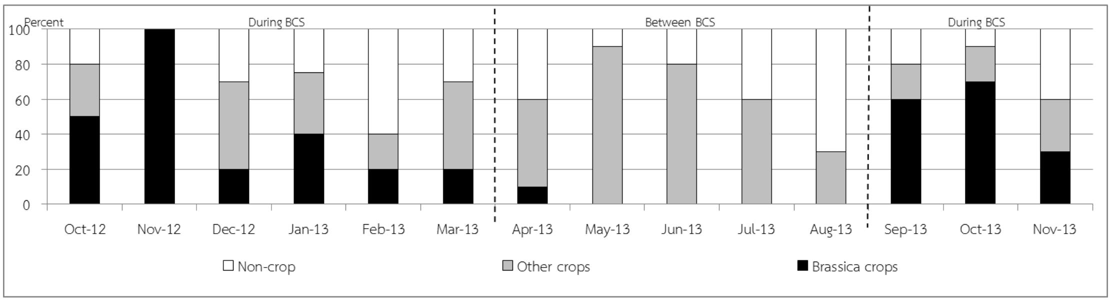

Figure 4-4 Percentage of plantation, *Brassica* crops, other crops and non-crop on LN1 (total area 3200 m^2) during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013)

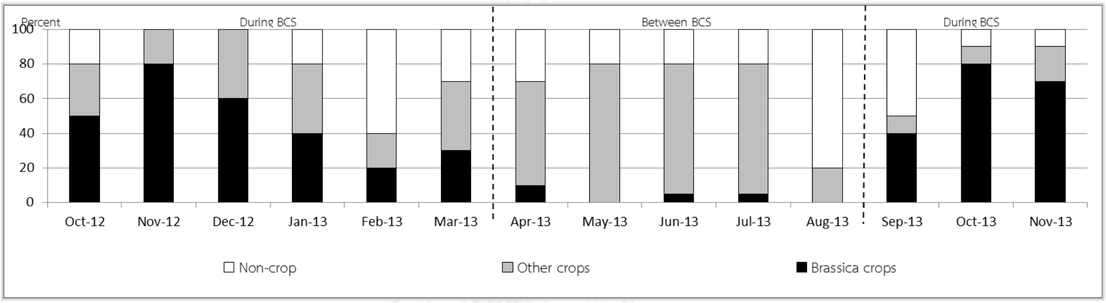

Figure 4-5 Percentage of plantation, *Brassica* crops, other crops and non-crop on LN2 (total area 2400 m^2) during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013)

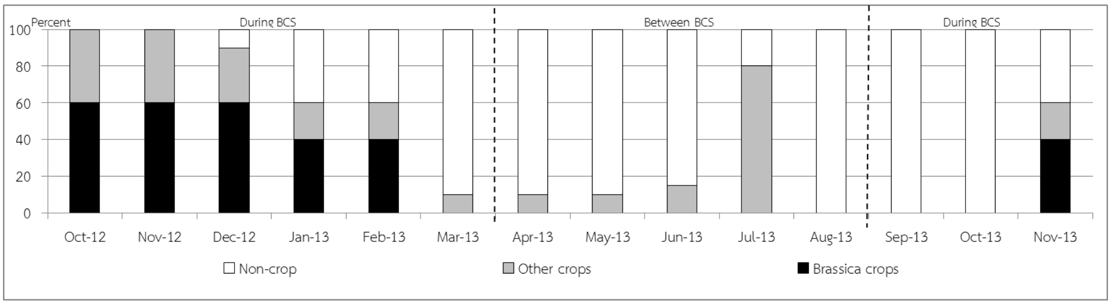

Figure 4-6 Percentage of plantation, *Brassica* crops, other crops and non-crop on LN3 (total area 800 m^2) during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013)

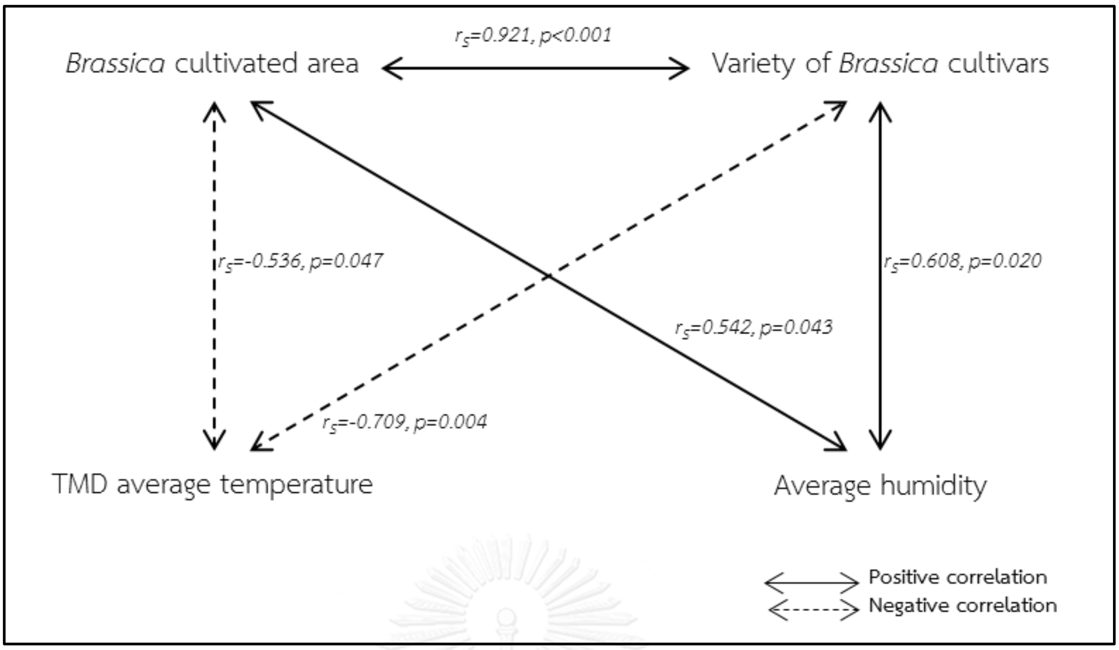

Figure 4-7 Spearman correlations between the physical factors and plantation based on TMD average temperature, average humidity, *Brassica* cultivated area and variety of *Brassica* cultivars during and between *Brassica* cultivated seasons (October 2012-November 2013)

4.3 Lepidopteran pests

Total of nine species from seven families of the lepidopteran pests were recorded from all study sites at Lainan Subdistrict, Wiang Sa District, Nan Province: *Spodoptera litura* (Fabricius, 1775) (Noctuidae), *Thychoplusia ni* (Hubner, 1800-1803) (Noctuidae), *Helicoverpa armigera* (Hubner, 1809) (Noctuidae), *Plutella xylostella* (Linnaeus, 1758) (Yponomeutidae), *Pieris rapae* (Linnaeus, 1758) (Pieridae), *Hellula undalis* (Fabricius, 1794) (Pyralidae), *Crocidolomia pavonana* (Fabricius, 1794) (Crambidae), *Archips micaceana* (Walker, 1863) (Tortricidae), and *Orvasca subnotata* Walker, 1865 (Erebidae) (Table 4-1).

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Table 4-1 Larvae of the lepidopteran pests collected from *Brassica* crops in the three study sites (LN1, LN2 and LN3) at Lainan Subdistrict, Wiang Sa District, Nan Province during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

No.	Species	Picture	Study site		
			LN1	LN2	LN3
1	*Spodoptera litura* Family Noctuidae		/	/	/
2	*Thychoplusia ni* Family Noctuidae		/	/	/
3	*Helicoverpa armigera* Family Noctuidae		/	/	

Table 4.1 (continue) Larvae of the lepidopteran pests collected from *Brassica* crops in the three study sites (LN1, LN2 and LN3) at Lainan Subdistrict, Wiang Sa District, Nan Province during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

No.	Species	Picture	Study sites		
			LN1	LN2	LN3
4	*Plutella xylostella* Family Yponomeutidae		/	/	/
5	*Pieris rapae* Family Pieridae		/	/	/
6	*Hellula undalis* Family Pyralidae		/	/	/

Table 4.1 (contineu) Larvae of the lepidopteran pests collected from *Brassica* crops in the three study sites (LN1, LN2 and LN3) at Lainan Subdistrict, Wiang Sa District, Nan Province during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

No.	Species	Picture	Study site		
			LN1	LN2	LN3
7	*Crocidolomia pavonana* Family Crambidae			/	/
8	*Archips micaceana* Family Tortricidae			/	/
9	*Orvasca subnotata* Family Erebidae		/	/	/

Among the cultivars of *Brassica* crops, there were different numbers of the lepidopteran pests collected from the plants (Figure 4-8). For cabbages, *S. litura*, *P. xylostella*, *T ni* and *P. rapae* were the highest collected lepidopteran pests (Figure 4-9 A). Broccoli was the dominant *Brassica* crops in the study areas and was attacked by all nine species of lepidopteran pests recorded from this study (Figure 4-9 B). In cauliflower, the *S. litura* was the dominant lepidopteran pest (Figure 4-9 C), while *C. pavonana* was the dominant lepidopteran pests in Chinese kale and pak choi (Figure 4-9 D and 4-9 E).

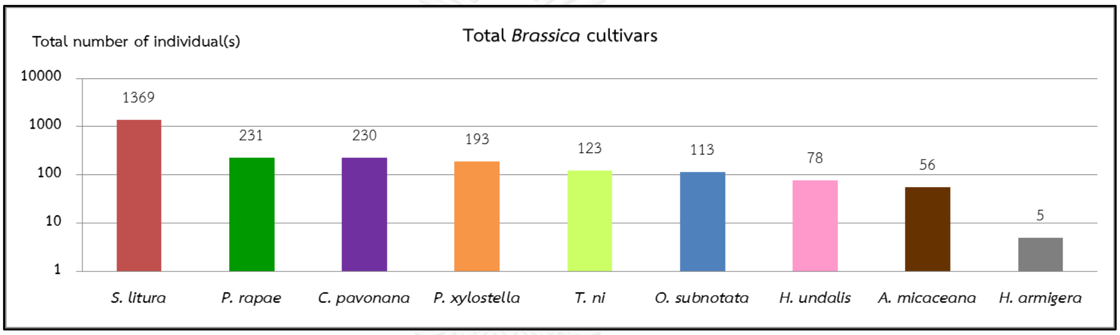

Figure 4-8 Number of each species of the lepidopteran pests collected from total *Brassica* cultivars in all study sites at Lainan Subdistrict, Wiang Sa District, Nan Province, during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

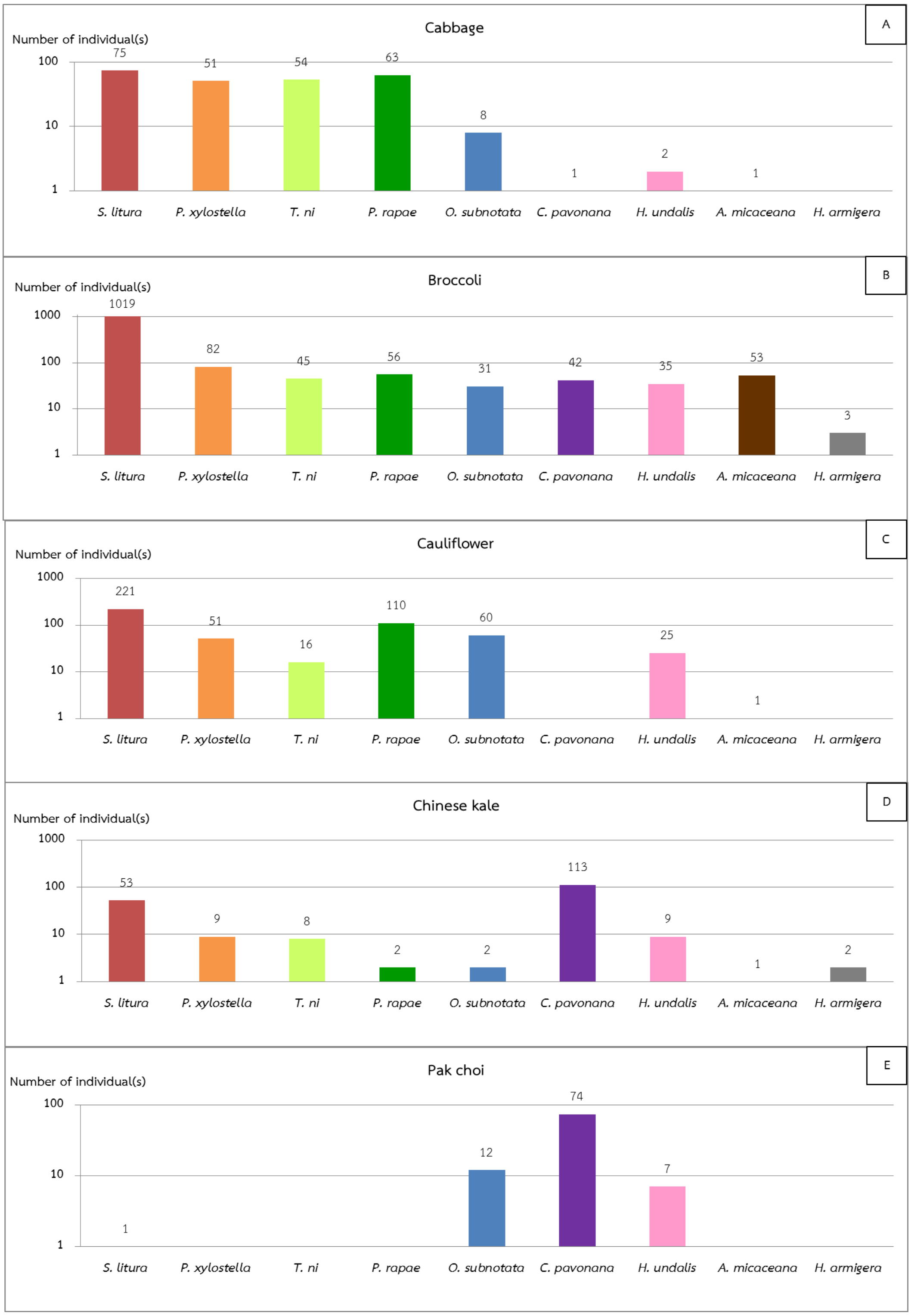

Figure 4-9 Number of each species of the lepidopteran pests collected from *Brassica* crops in all study sites; A, cabbage; B, broccoli; C, cauliflower; D, Chinese kale and E, pak choi at Lainan Subdistrict, Wiang Sa District, Nan Province, during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

The abundance and frequency of the lepidopteran pests were analyzed with the prevalence index to classify the status of major and minor groups of lepidopteran pests. The major pest group was *S. litura*, *P. xylostella*, *T. ni* and *P. rapae* (Prevalence index = 3.11, 1.67, 1.67 and 1.56, respectively). The minor pest group was *O. subnotata, C. pavonana*, *H. undalis*, *A. micaceana*, *H. armigera* (Prevalence index = 1.22, 1.00, 0.78, 0.67 and 0.11, respectively) (Figure 4-10).

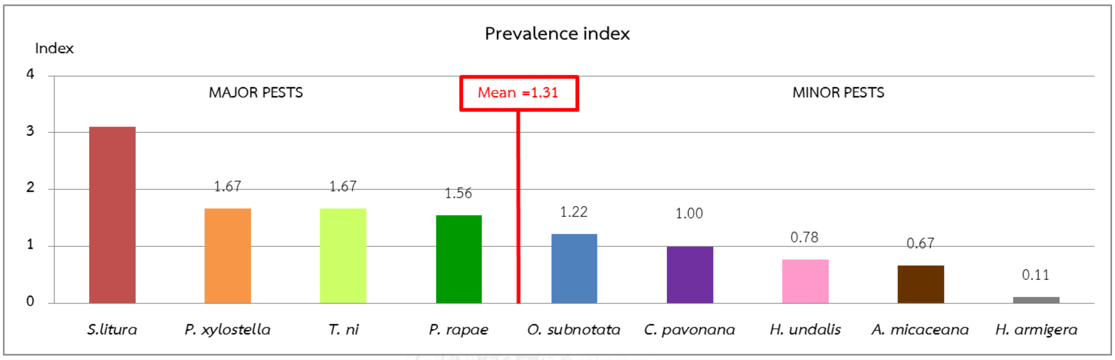

Figure 4-10 The prevalence index of the lepidopteran pests

Number of lepidopteran pests among each study sites are no significantly difference on Kruskal-Wallis One Way Analysis of Variance on Ranks Test, except *T. ni* which was significantly different between LN2 and LN3

S. litura	(*H=4.063, df=2, p=0.131*)	Figure 4-11
P. xylostella	(*H=4.712, df=2, p=0.095*)	Figure 4-12
T. ni	(*H=7.068, df=2, p=0.029*)	Figure 4-13
P. rapae	(*H=0.808, df=2, p=0.668*)	Figure 4-14
O. subnotata	(*H=2.504, df=2, p=0.286*)	Figure 4-15
C. pavonana	(*H=3.025, df=2, p=0.220*)	Figure 4-16
H. undalis	(*H=3.195, df=2, p=0.202*)	Figure 4-17
A. micaceana	(*H=2.971, df=2, p=0.226*)	Figure 4-18
H. armigera	(*H=1.043, df=2, p=0.594*)	Figure 4-19

In additional to the variety of the lepidopteran pests (Figure 4-20) and their total number on each study site (Figure 4-21), there is no significant difference on Kruskall-Wallis, $p=0.131$ and $p=0.085$, respectively.

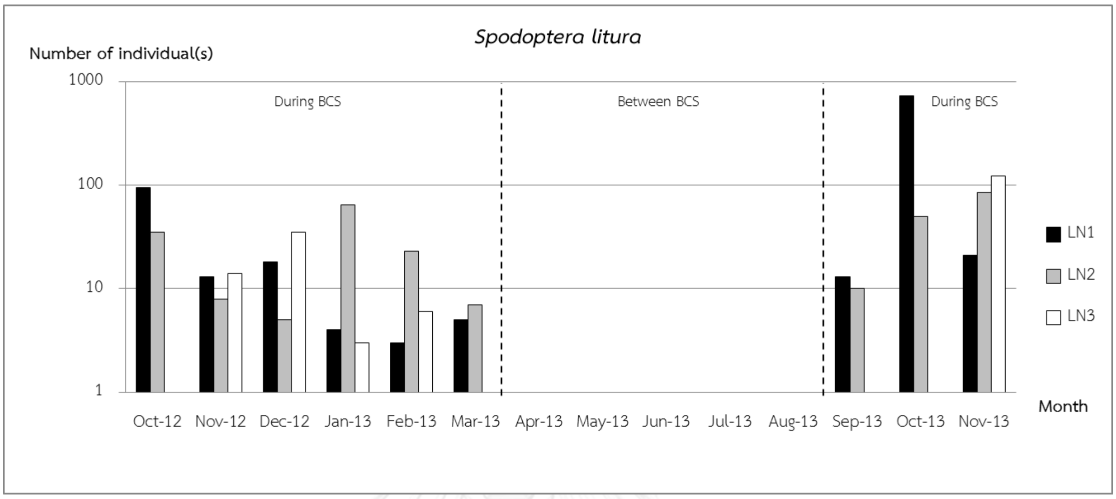

Figure 4-11 Number of *S. litura* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

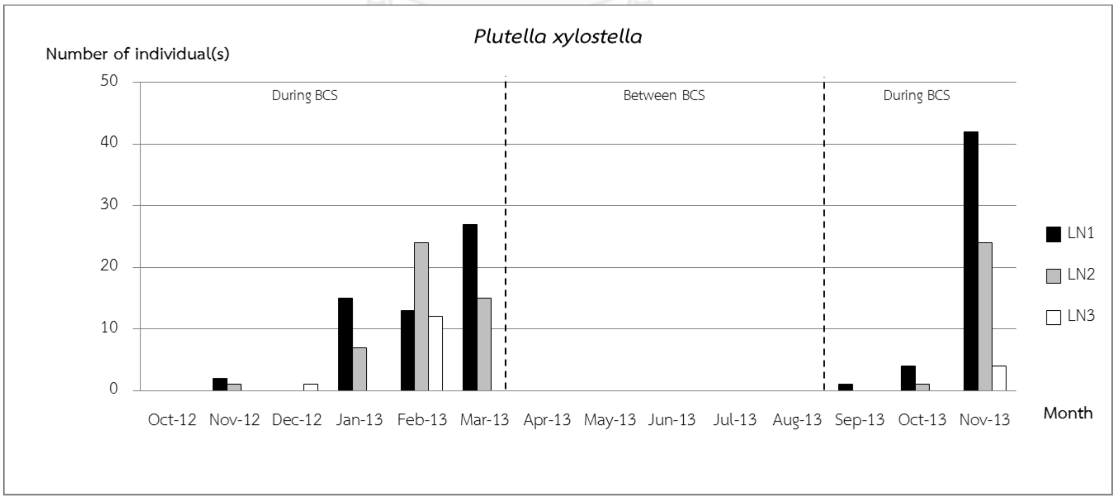

Figure 4-12 Number of *P. xylostella* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

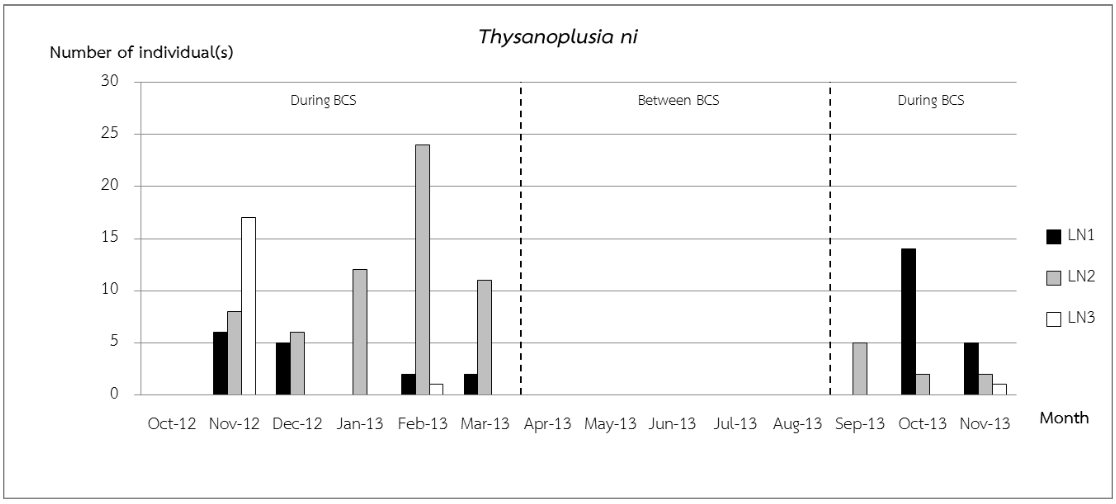

Figure 4-13 Number of *T. ni* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

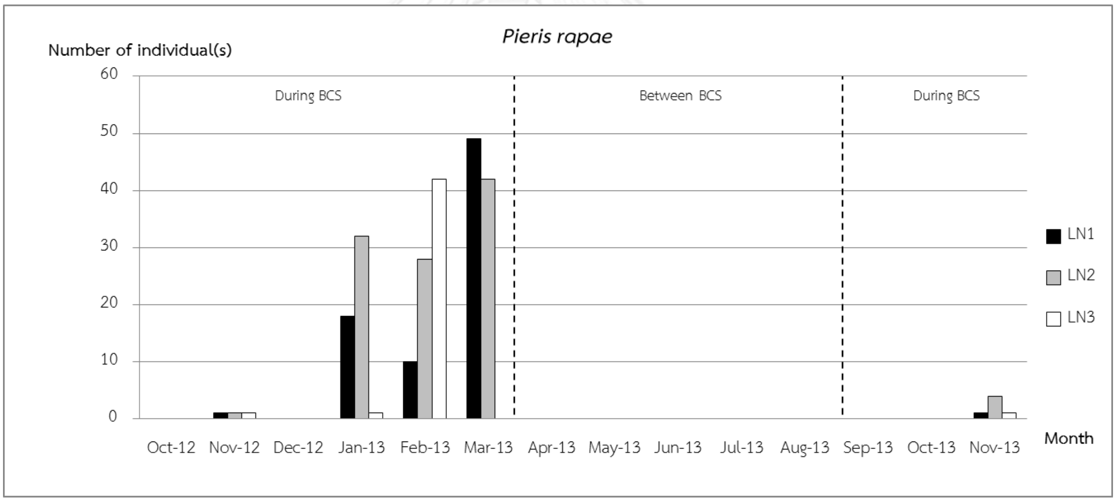

Figure 4-14 Number of *P. rapae* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

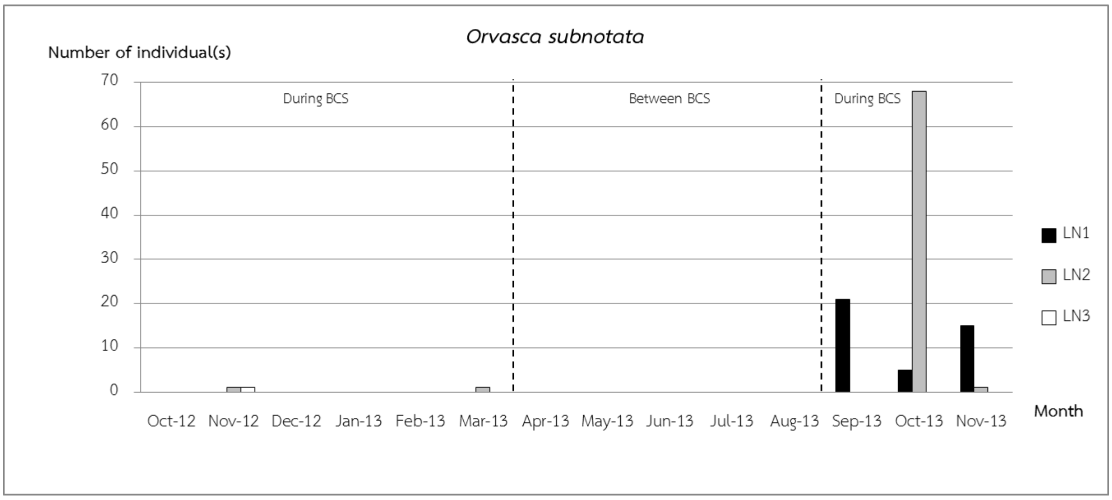

Figure 4-15 Number of *O. subnotata* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

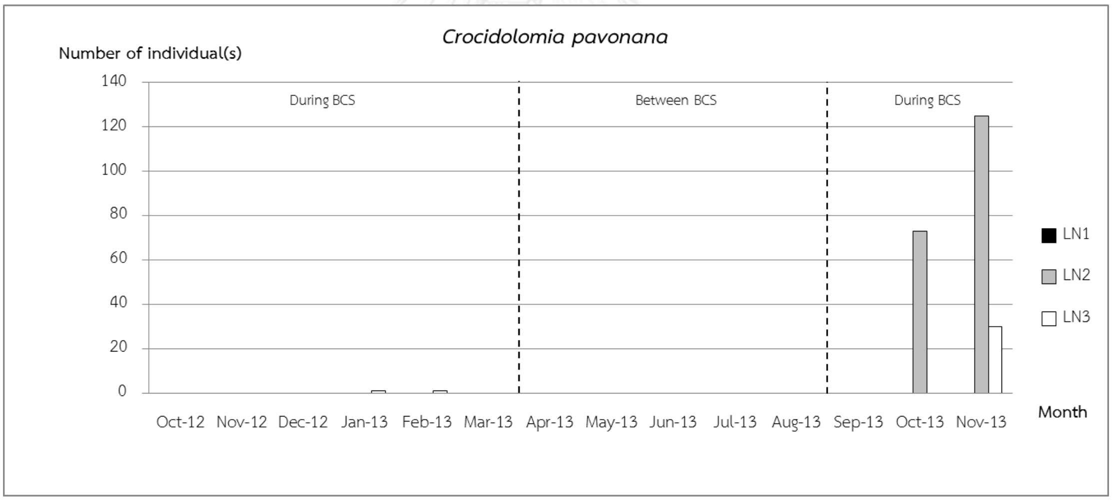

Figure 4-16 Number of *C. pavonana* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

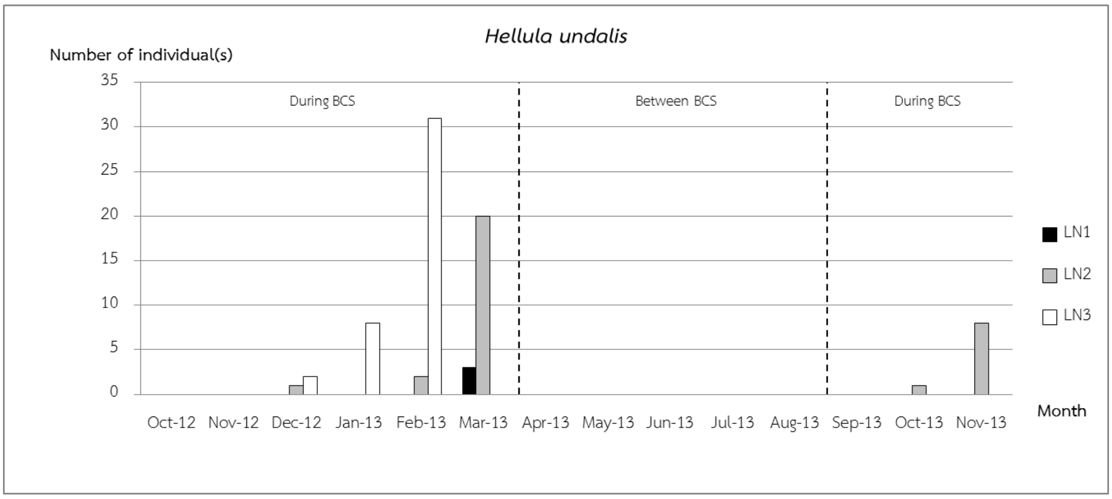

Figure 4-17 Number of *H. undalis* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

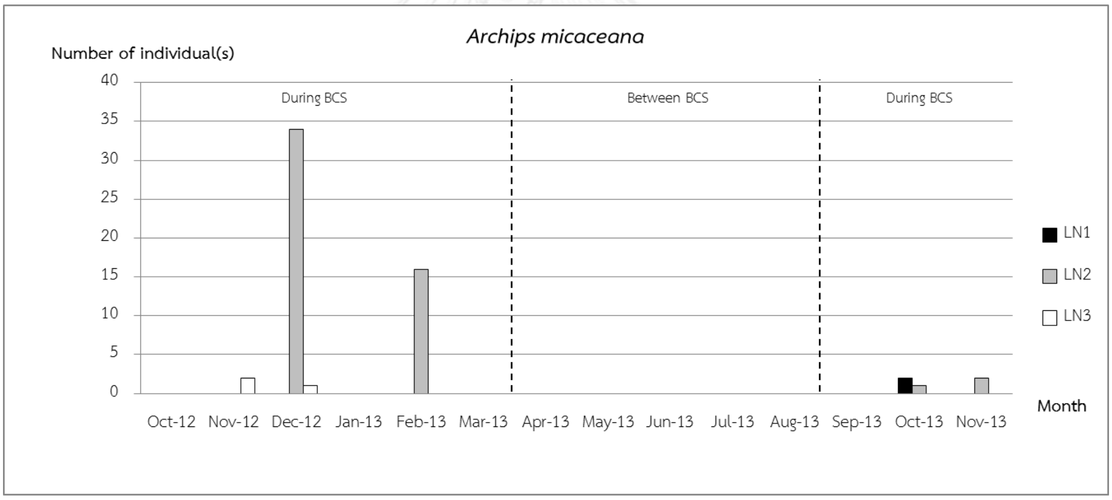

Figure 4-18 Number of *A. micaceana* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

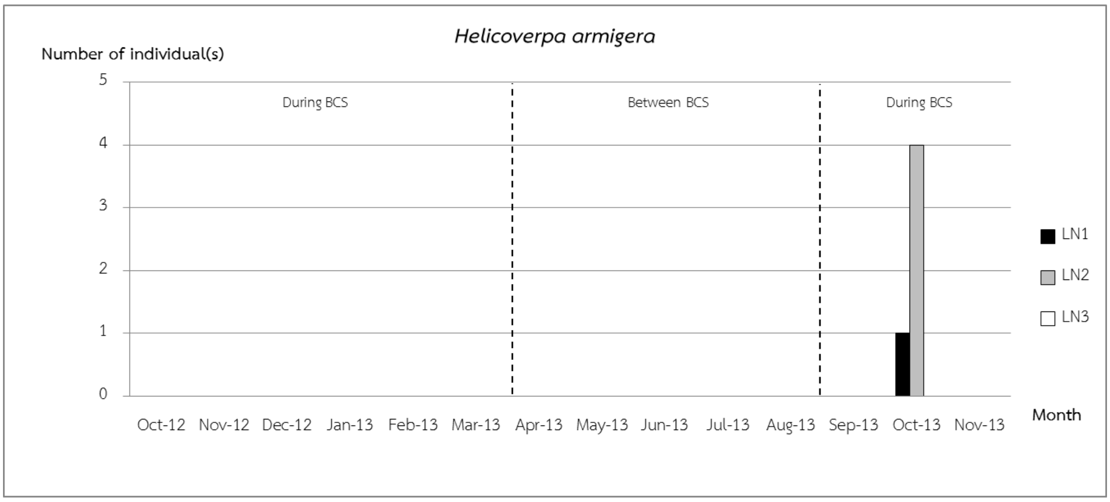

Figure 4-19 Number of *H. armigera* recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

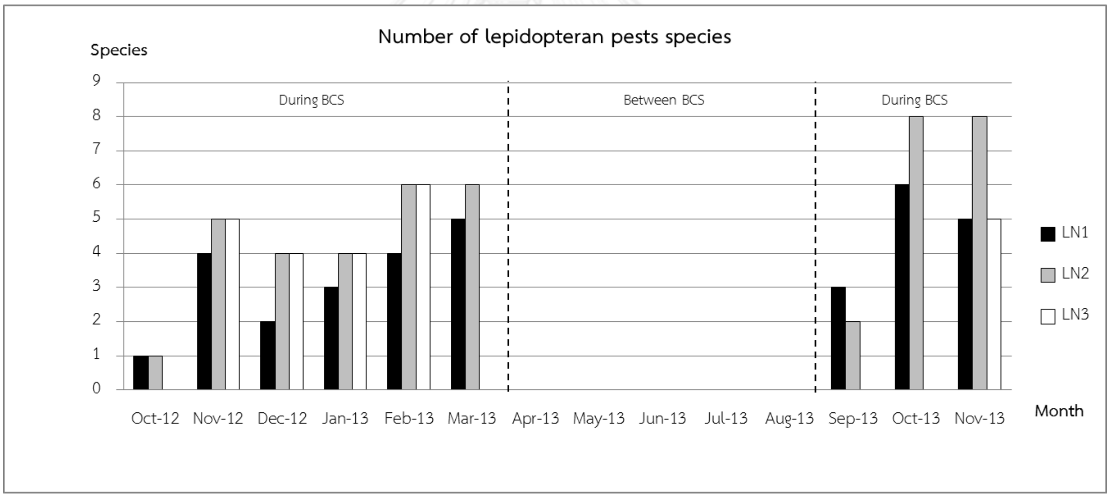

Figure 4-20 Number of lepidopteran pest species recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

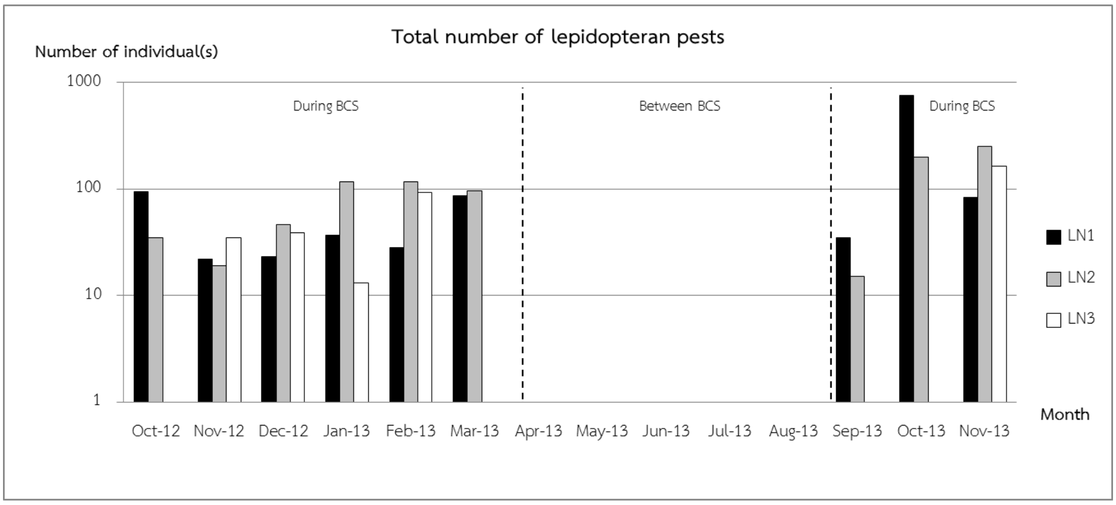

Figure 4-21 Total number of lepidopteran pests recorded during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

Total number of the lepidopteran pests from all study sites (LN1+LN2+LN3) was shown in Table 4-2. *Spodoptera litura* was the dominant species, it was found every month during *Brassica* cultivated seasons. The highest abundance of *S. litura* was 779 larvae and pupae in October 2013. The abundance of *P. xylostella* ranged from 1-70 individuals per month during *Brassica* seasons. *Pieris rapae* was dominant during January - March 2013, with the numbers of 51, 80 and 91 individuals, in January, February and March, respectively. *Thysanoplusia ni* was commonly found in low abundance during the *Brassica* cultivated seasons. *Crocidolomia pavonana* had been recorded with highly abundance in October and November 2013 (73 and 155 individuals, respectively). The abundance of *O. subnotata* was highest in October 2013 with 73 collected larvae and pupae, while *A. micaceana*, *H. undalis* and *H. armigera* are the uncommon species of lepidopteran pests at this locality.

The composition of lepidopteran pests on the *Brassica* agricultural areas at Lainan Subdistrict, Wiang Sa District, Nan Province was highly diverse in February 2013 (Shannon-Weiner's Index = 1.69 and Simpson's Index = 0.21) (Table 4-2). The highest number of lepidopteran pests were recorded in October 2013, with 955 larvae and pupae, while, diversity of the lepidopteran pests in this month was low (Shannon-Weiner's Index = 0.71 and Simpson's Index = 0.68).

Table 4-2 Number of lepidopteran pests and the diversity indices during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

SPECIES	2012			2013					
	OCT	NOV	DEC	JAN	FEB	MAR	SEP	OCT	NOV
S. litura	130	35	58	72	32	12	23	779	228
P. xylostella	-	3	1	22	49	42	1	5	70
P. rapae	-	3	-	51	80	91	-	-	6
H. undalis	-	-	3	8	33	23	-	1	8
T. ni	-	31	11	12	27	13	5	16	8
C. pavonana	-	-	-	1	1	-	-	73	155
A. micaceana	-	2	35	-	16	-	-	3	2
O. subnotata	-	2	-	-	-	1	21	73	16
H. armigera	-	-	-	-	-	-	-	5	-
Total No. of individuals	130	76	108	166	238	182	50	955	493
Number of species	1	6	5	6	7	6	4	8	8
Shannon-Wiener's Index	0	1.17	1.07	1.36	1.69	1.34	1.03	0.71	1.32
Simpson's Index	1	0.38	0.40	0.31	0.21	0.33	0.40	0.68	0.33

Abundance of *S. litura* was positively correlated to the variety of *Brassica* cultivars (Kruskall-Wallis; r_S*=0.837, p=0.002*). However, the other important lepidopteran pests were not significantly correlated to the physical factors and *Brassica* crops plantating area, but they had complex correlations. *P. xylostella* was positively correlated to *P. rapae* (r_S*=0.795, p=0.006*), *H. undalis* was positively correlated to *P. xylostella* (r_S*=0.821, p=0.004*), *H. undalis* was positively correlated to *P. rapae* (r_S*=0.818, p=0.004*), and *C. pavonana* was positively correlated to *P. xylostella* (r_S*=0.700, p=0.030*) (Figure 4-22).

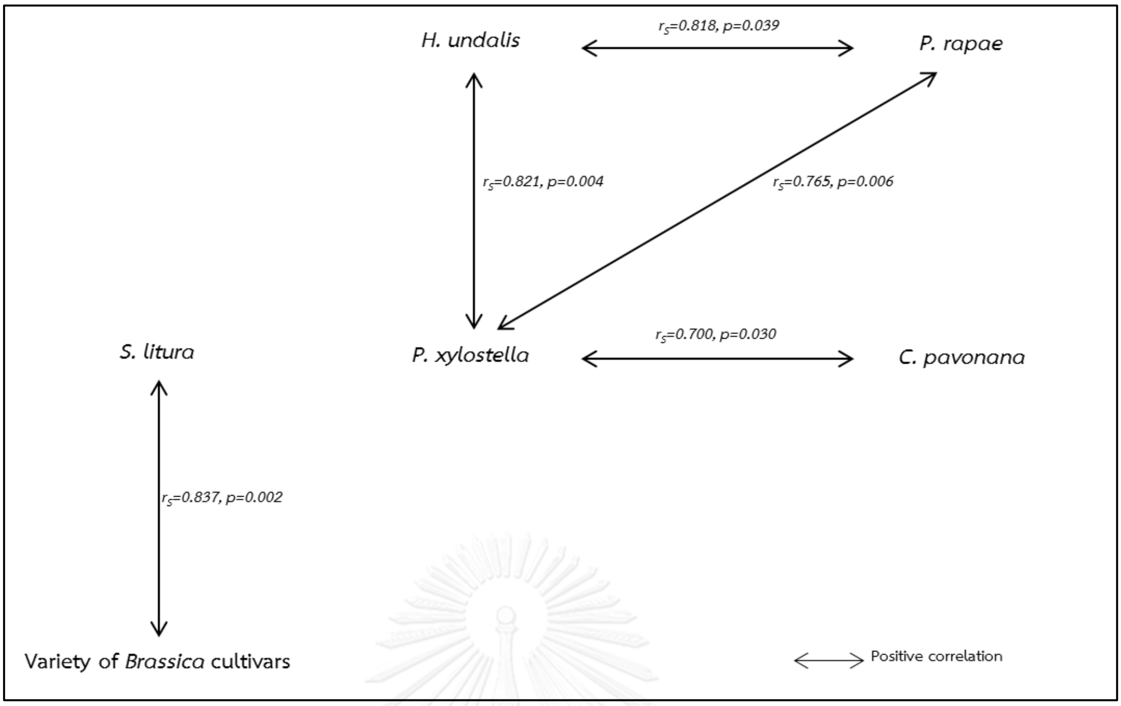

Figure 4-22 Spearman correlations between the lepidopteran pest – *Brassica* crops and lepidopteran pests - lepidopteran pests during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

4.4 Beneficial parasitoids

Fourteen species of beneficial parasitoids of which thirteen species area parasitic wasps and one species of parasitic fly, were found in the lepidopteran pests rearing collected from the three *Brassica* cultivation areas at Lainan Subdistrict, Wiang Sa District, Nan Province. Namely, *Microplitis* sp. (Braconidae), *Mesochorus* sp. (Ichneumonidae), *Diadegma* sp. (Ichneumonidae), *Charops* sp. (Ichneumonidae), *Metopius* sp. (Ichneumonidae), *Dolichogenidae* sp. (Braconidae), *Therophilus* sp. (Ichneumonidae), *Chelonus* sp. (Braconidae), *Cotesia* spp. (Braconidae), *Snellius* sp. (Braconidae), *Trathala* sp. (Ichneumonidae), cryptinid wasp (Ichneumonidae), *Brachymeria* sp. (Chalcididae) and tachinid fly (Tachinidae) (Table 4-3).

Table 4-3 Parasitoids of the lepidopteran pests (host rearing method) collected from *Brassica* crops in the three study sites (LN1, LN2 and LN3) at Lainan Subdistrict, Wiang Sa District, Nan Province during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

No.	Parasitoids	Hosts	Study sites		
			LN1	LN2	LN3
Order Hymenoptera: Family Braconidae					
1	*Microplitis* sp.	*S. litura*	/	/	/
2	*Dolichogenidae* sp.	*C. pavonana*		/	
3	*Chelonus* sp.	*C. pavonana*		/	
4	*Cotesia* spp.	*P. xylostella* and *T. ni*	/	/	
5	*Snellius* sp.	*T. ni*		/	
Order Hymenoptera: Family Ichneumonidae					
6	*Mesochorus* sp.	*S. litura*	/	/	/
7	*Diadegma* sp.	*S. litura*			/
8	*Charops* sp.	*S. litura*		/	/
9	*Metopius* sp.	*S. litura*			/
10	*Therophilus* sp.	*C. pavonana*		/	/
11	*Trathala* sp.	*H. undalis*	/	/	/
12	cryptinid wasp	*O. subnotata*	/		
Order Hymenoptera: Family Chalcididae					
13	*Brachymeria* sp.	*P. rapae*	/	/	
Order Diptera: Family Tachinidae					
14	tachinid fly	*S. litura*	/	/	/

The list of beneficial parasitoids of the lepidopteran pests on *Brassica* agricultural areas at the study sites were recorded during the *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013) and are shown on Tables 4-4, 4-5 and 4-6 (including primary parasitoids, hyperparasitoids, solitary parasitoids and gregarious parasitoids). Fourteen species of beneficial parasitoids and their life histories on their hosts have been recorded. However, there was no significant difference on the number of fourteen beneficial parasitoids species among three study sites during the *Brassica* cultivated seasons.

Microplitis sp.	(*H=0.823, df=2, p=0.663*)	Figure 4-23
Mesochorus sp.	(*H=1.667, df=2, p=0.434*)	Figure 4-24
Diadegma sp.	(*H=2.000, df=2, p=0.368*)	Figure 4-25
Charops sp.	(*H=2.243, df=2, p=0.326*)	Figure 4-26
Metopius sp.	(*H=2.000, df=2, p=0.368*)	Figure 4-27
tachinid fly	(*H=0.000, df=2, p=1.000*)	Figure 4-28
Dolichogenidae sp.	(*H=2.000, df=2, p=0.368*)	Figure 4-29
Therophilus sp.	(*H=2.280, df=2, p=0.320*)	Figure 4-30
Chelonus sp.	(*H=2.000, df=2, p=0.368*)	Figure 4-31
Cotesia spp.	(*H=2.265, df=2, p=0.322*)	Figure 4-32
Snellius sp.	(*H=2.000, df=2, p=0.368*)	Figure 4-33
Trathala sp.	(*H=0.630, df=2, p=0.730*)	Figure 4-34
cryptinid wasp	(*H=2.000, df=2, p=0.368*)	Figure 4-35
Brachymeria sp.	(*H=1.043, df=2, p=0.594*)	Figure 4-36

Number of parasitoid species, total number of parasitoids and parasitism rates each month were not significantly different among the three study sites (Figure 4-37, *H=1.811, df=2, p=0.404*; Figure 4-38, *H=1.560, df=2, p=0.458* and Figure 4-39, *H=0.929, df=2, p=0.628*, respectively).

Table 4-4 List of beneficial parasitoids recorded from host rearing, with the number of lepidopteran pests, successful parasitized of parasitoids and parasitism rates (PR) at Lainan Subdistrict, Wiang Sa District, Nan Province, during October - December, 2012

Host	October 2012			November 2012			December 2012		
	No. of Pest	Parasitoids Species	Parasitoids No. PR (%)	No. of Pest	Parasitoids Species	Parasitoids No. PR (%)	No. of Pest	Parasitoids Species	Parasitoids No. PR (%)
S. litura	130	*Microplitis* sp.	8 6.2%	35	*Microplitis* sp.	4 11.4%	58	*Microplitis* sp.	6 10.3%
		Unparasitized	122 93.8%		Unparasitized	31 88.6%		*Mesochorus* sp.	3 5.2%
								Metopius sp.	1 1.7%
								tachinid fly	1 1.7%
								Unparasitized	47 81.0%
P. xylostella	-			3			1		
P. rapae	-			3			-		
H. undalis	-			-			3		
C. pavonana	-			-			-		
A. micaceana	-			2			35		
T. ni	-			31			11		
O. subnotata	-			2			-		
H. armigera	-			-			-		
Shannon-Wiener's Index	0			0			0.90		
Simpson's Index	1			1			0.46		

Table 4-5 List of beneficial parasitoids recorded from host rearing, with the number of lepidopteran pests, successful parasitized of parasitoids and parasitism rates (PR) at Lainan Subdistrict, Wiang Sa District, Nan Province, during January - March, 2013

Host	January 2013			February 2013			March 2013		
	No. of Pest	Parasitoids		No. of Pest	Parasitoids		No. of Pest	Parasitoids	
		Species	No. PR (%)		Species	No. PR (%)		Species	No. PR (%)
S. litura	72	*Microplitis* sp.	11 15.3%	32	*Microplitis* sp.	3 9.4%	12	*Microplitis* sp.	3 25.0%
		Mesochorus sp.	1 1.4%		Unparasitized	29 90.6%		*Mesochorus* sp.	1 8.3%
		Unparasitized	60 83.3%					Unparasitized	8 66.7%
P. xylostella	22			49	*Cotesia* sp.	5 10.2%	42	*Cotesia* sp.	2 4.8%
					Unparasitized	44 89.8%		Unparasitized	40 95.2%
P. rapae	51			80			91	*Brachymeria* sp.	7 7.7%
								Unparasitized	84 92.3%
H. undalis	8	*Trathala* sp.	1 12.5%	33	*Trathala* sp.	12 36.4%	23	*Trathala* sp.	9 39.1%
		Unparasitized	7 87.5%		Unparasitized	21 63.6%		Unparasitized	14 60.9%
C. pavonana	1	*Therophilus* sp.	1 100%	1			-		
		Unparasitized	0 0.0%						
A. micaceana	-			16			-		
T. ni	12			27			13		
O. subnotata	-			-			1		
H. armigera	-			-			-		
Shannon-Wiener's Index	0.75			0.65			1.36		
Simpson's Index	0.63			0.44			0.30		

Table 4-6 List of beneficial parasitoids recorded from host rearing, with the number of lepidopteran pests, successful parasitized of parasitoids and parasitism rates (PR) at Lainan Subdistrict, Wiang Sa District, Nan Province, during September - November, 2013

Host	September 2013 No. of Pest	September 2013 Parasitoids Species	September 2013 Parasitoids No. PR (%)	October 213 No. of Pest	October 213 Parasitoids Species	October 213 Parasitoids No. PR (%)	November 2013 No. of Pest	November 2013 Parasitoids Species	November 2013 Parasitoids No. PR (%)
S. litura	23	*Microplitis* sp.	2 8.7%	779	*Microplitis* sp.	147 18.9%	228	*Microplitis* sp.	41 18.0%
		Mesochorus sp.	2 8.7%		*Mesochorus* sp.	8 1.0%		*Mesochorus* sp.	10 4.4%
		Unparasitized	19 82.6%		tachinid fly	1 0.1%		tachinid fly	1 0.4%
					Charops sp.	5 0.6%		*Charops* sp,	2 0.9%
					Diadegma sp.	1 0.1%		Unparasitized	174 76.3%
					Unparasitized	617 79.2%			
P. xylostella	1			5			70		
P. rapae	-			-			6		
H. undalis	-			1			8		
C. pavonana	0			73	*Therophilus* sp.	11 15.1%	155	*Therophilus* sp.	20 12.9%
					Dolichogenidae sp.	3 4.1%		*Chelonus* sp.	1 0.6%
					Unparasitized	59 80.8%		Unparasitized	134 86.5%
A. micaceana	-			3			2		
T. ni	5	*Snellius* sp.	1 20.0%	16	*Cotesia* sp.	1 6.3%	8		
		Unparasitized	4 80.0%		Unparasitized	15 93.8			
O. subnotata	21			73			16	cryptinid wasp	1 6.3%
								Unparasitized	15 93.8%
H. armigera	-			5			-		
Shannon -Wiener's Index	1.05			0.69			1.16		
Simpson's Index	0.36			0.70			0.39		

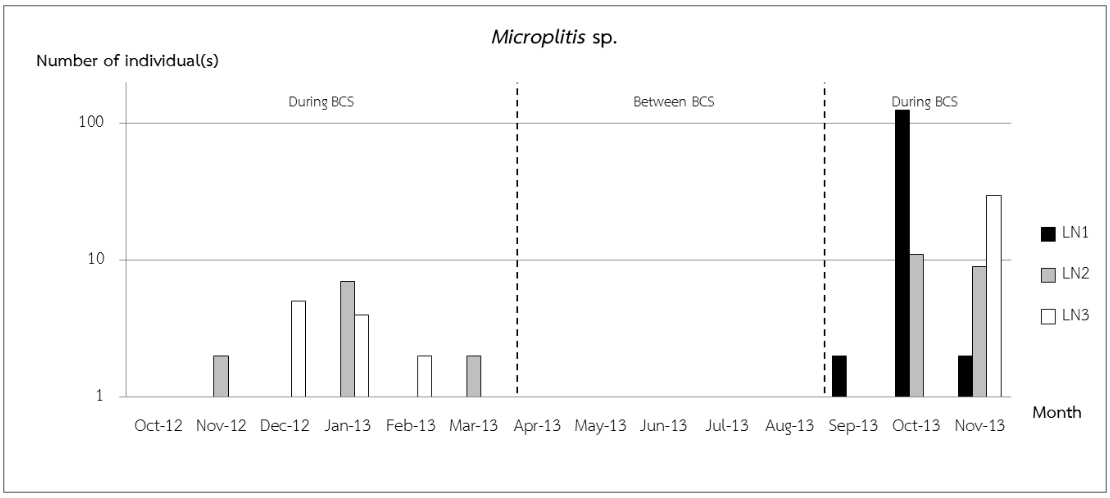

Figure 4-23 Number of *Microplitis* sp. emerged from *S. litura* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

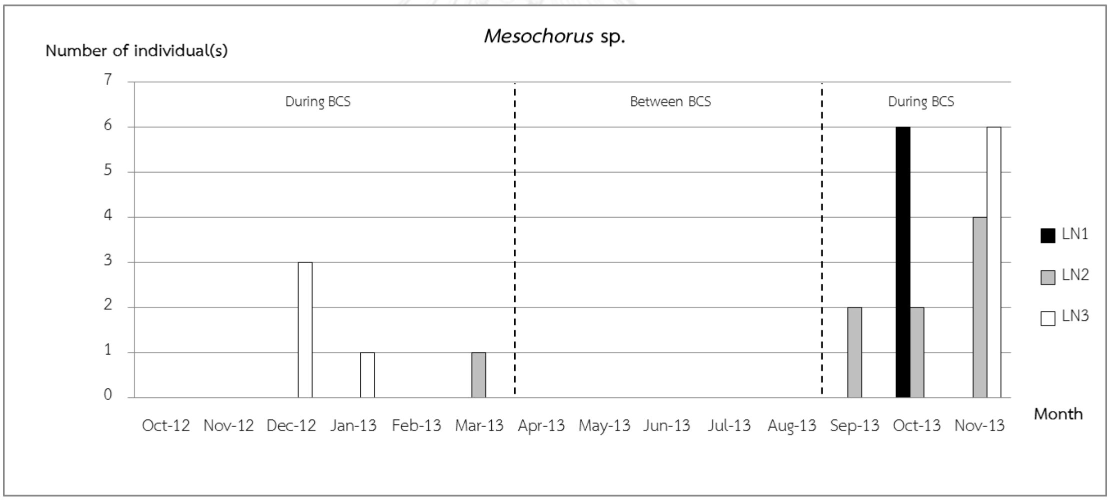

Figure 4-24 Number of *Mesochorus* sp. emerged from *S. litura* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

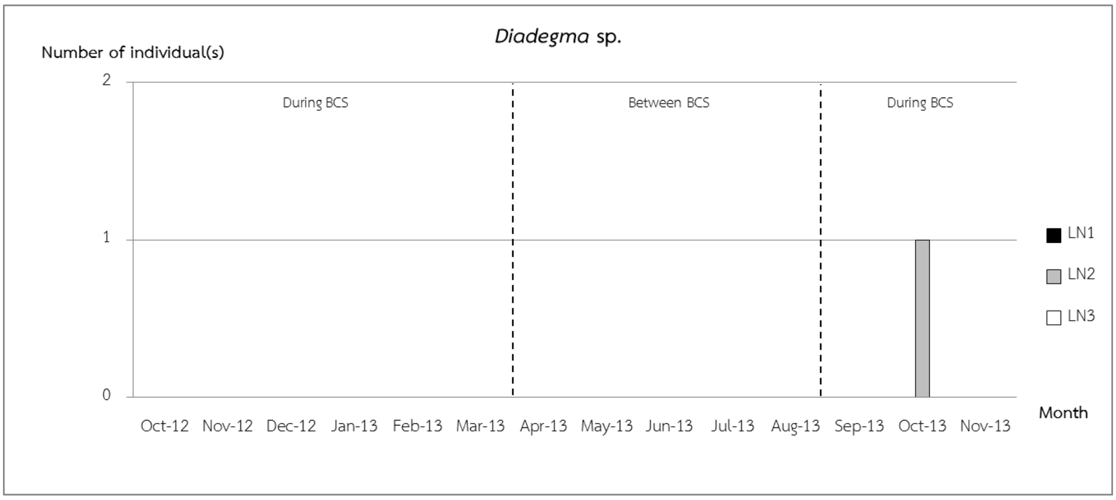

Figure 4-25 Number of *Diadegma* sp. emerged from *S. litura* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

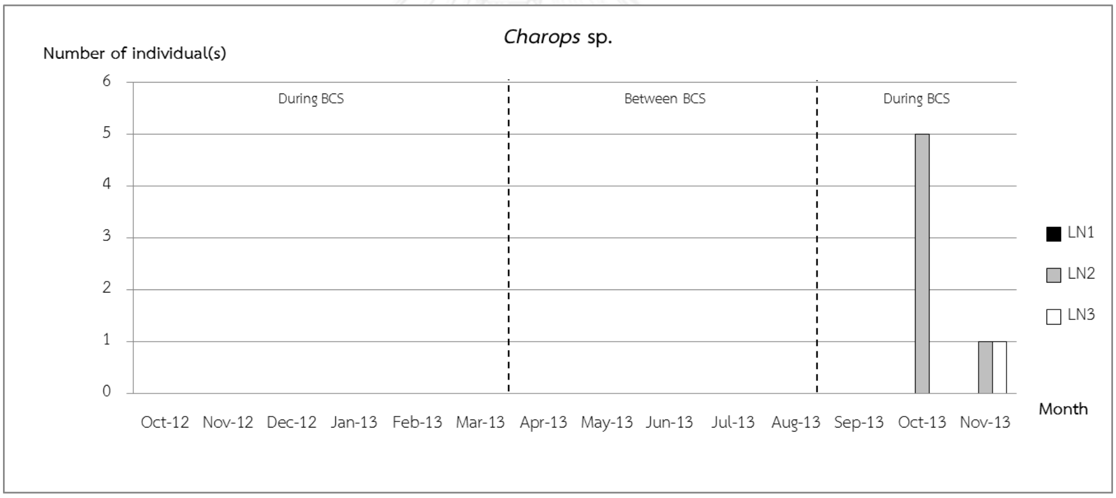

Figure 4-26 Number of *Charops* sp. emerged from *S. litura* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

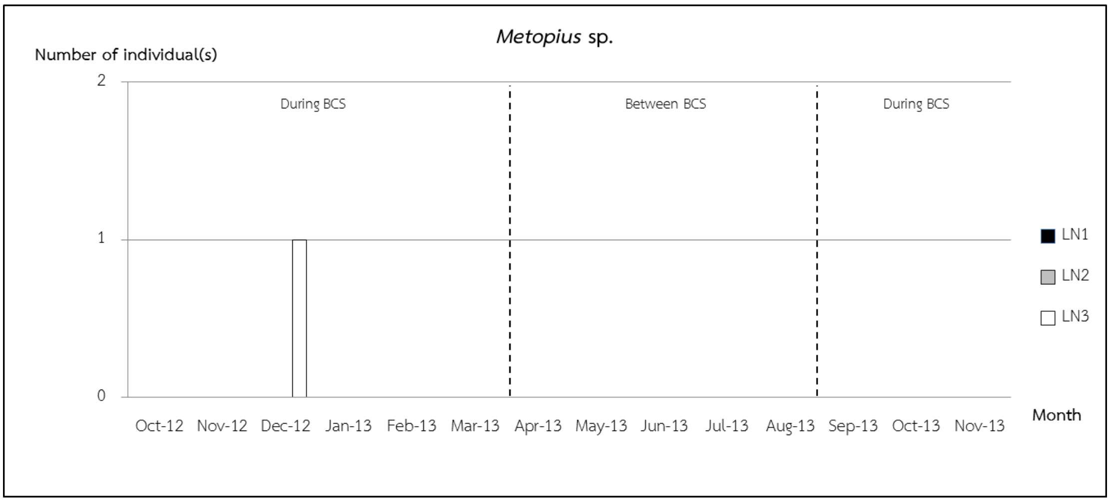

Figure 4-27 Number of *Metopius* sp. emerged from *S. litura* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

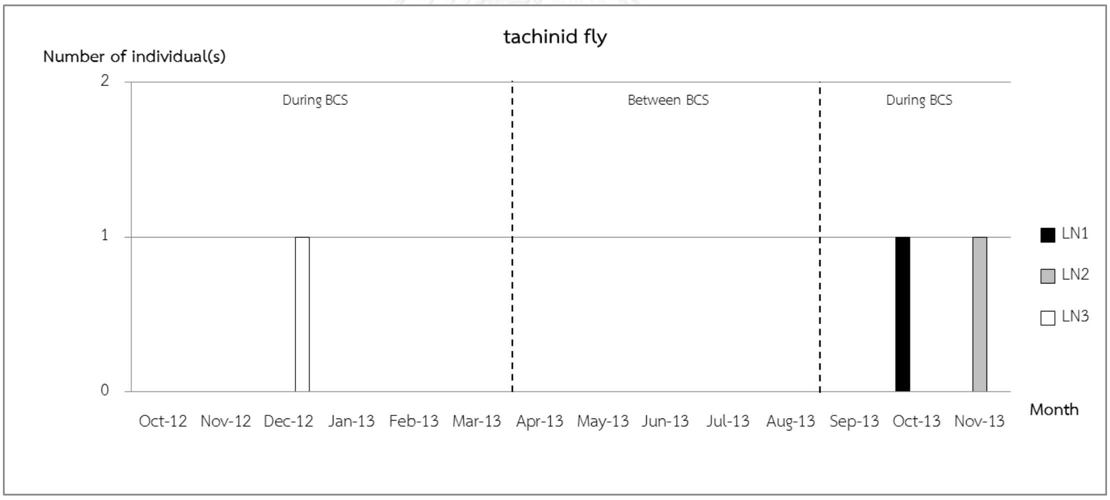

Figure 4-28 Number of tachinid fly emerged from *S. litura* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

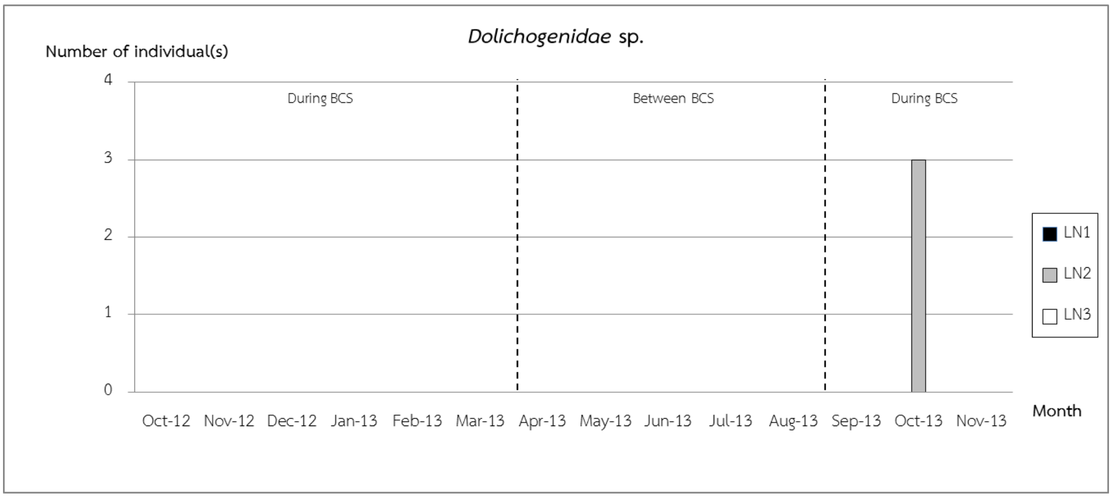

Figure 4-29 Number of *Dolichogenidae* sp. emerged from *C. pavonana* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

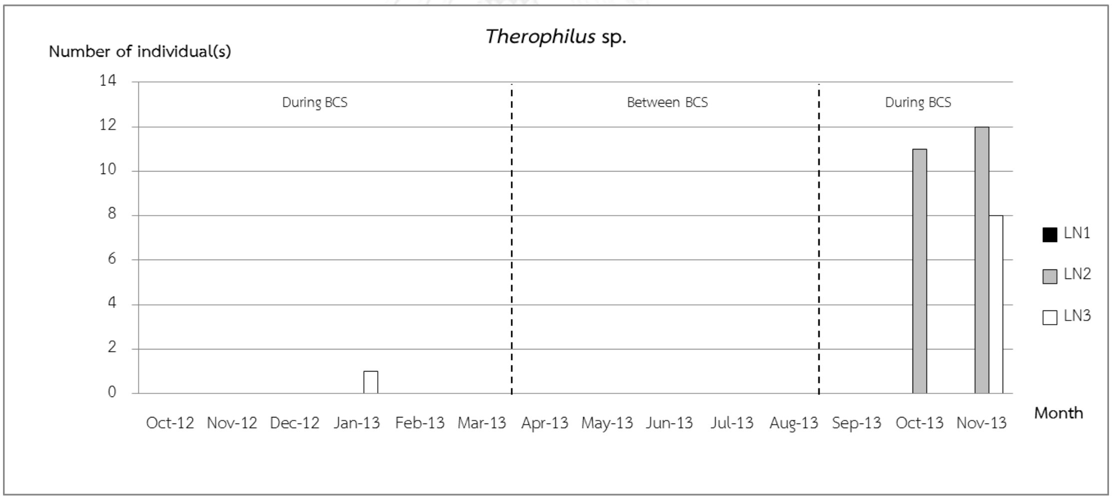

Figure 4-30 Number of *Therophilus* sp. emerged from *C. pavonana* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

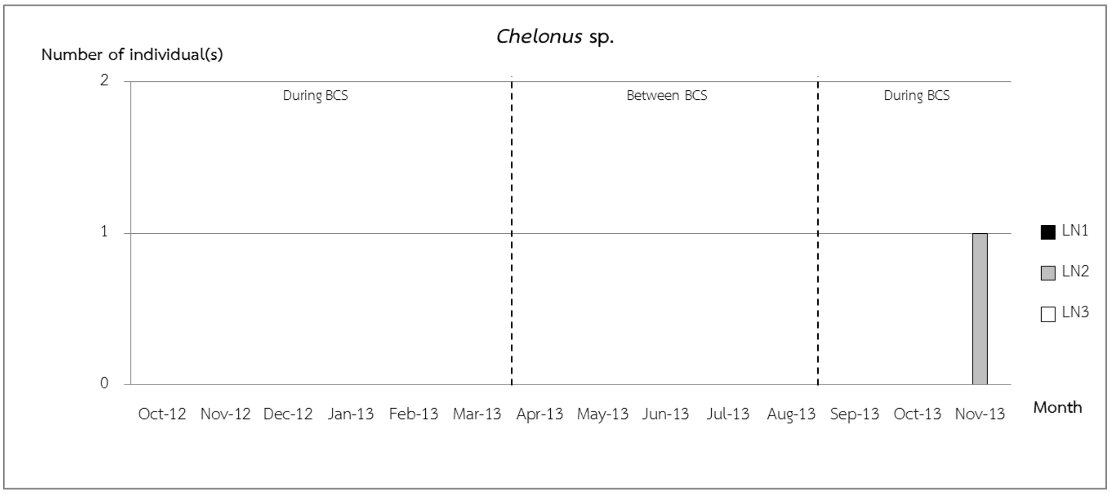

Figure 4-31 Number of *Chelonus* sp. emerged from *C. pavonana* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

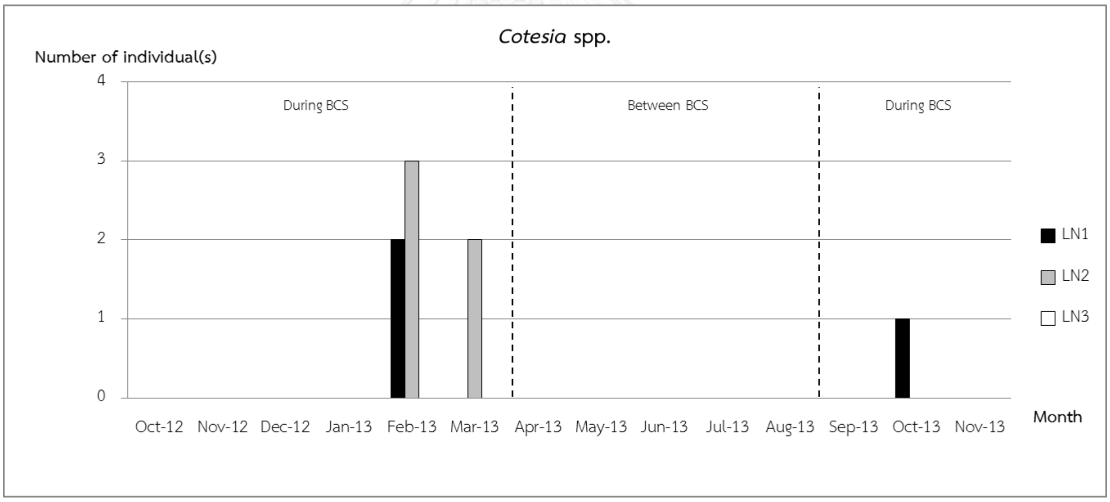

Figure 4-32 Number of *Cotesia* spp. emerged from *P. xylostella* and *T. ni* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

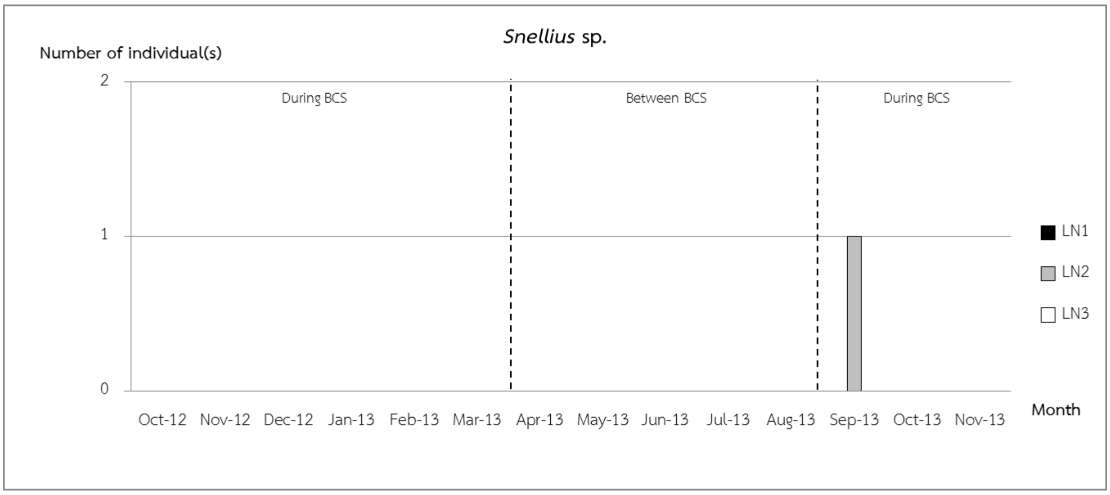

Figure 4-33 Number of *Snellius* sp. emerged from *T. ni* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

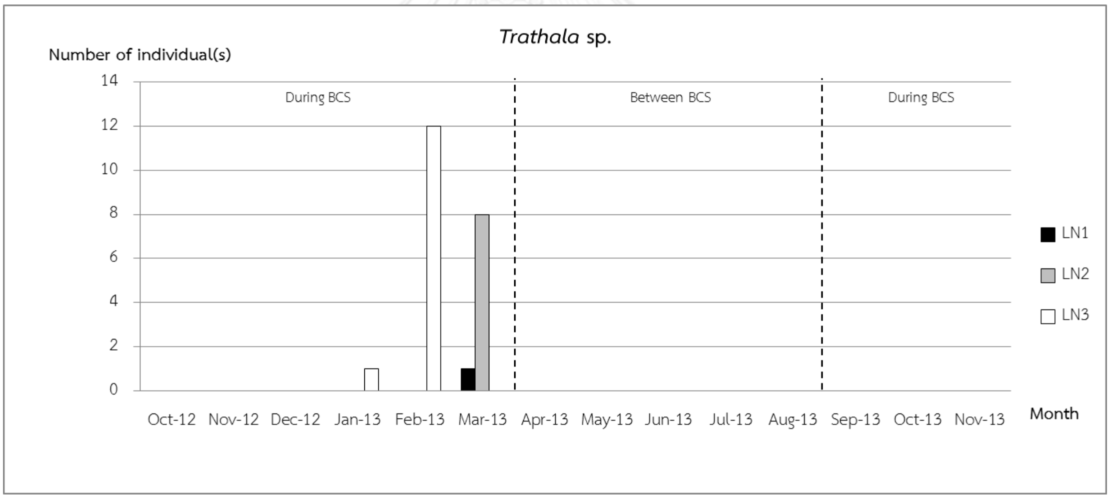

Figure 4-34 Number of *Trathala* sp. emerged from *H. undalis* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

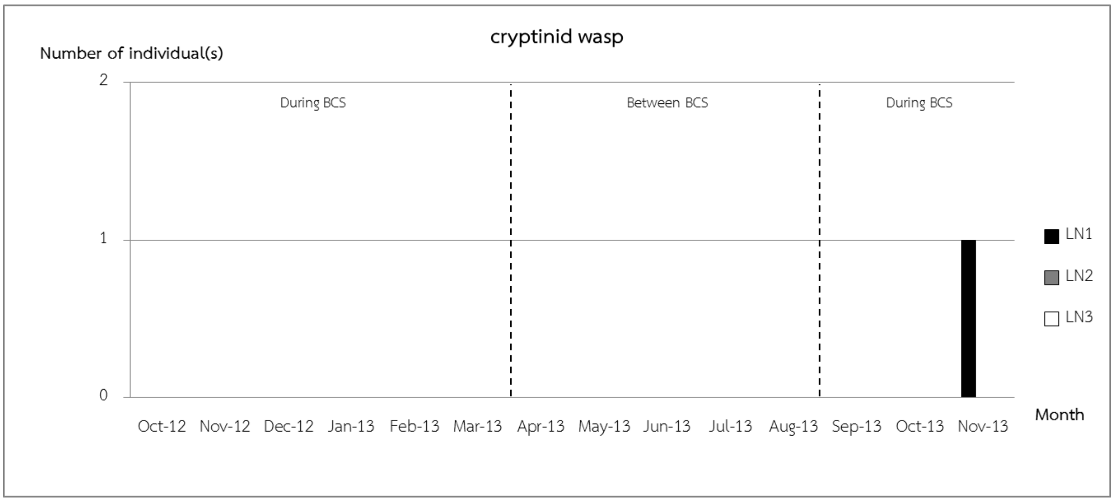

Figure 4-35 Number of cryptinid wasp emerged from *O. subnatata* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

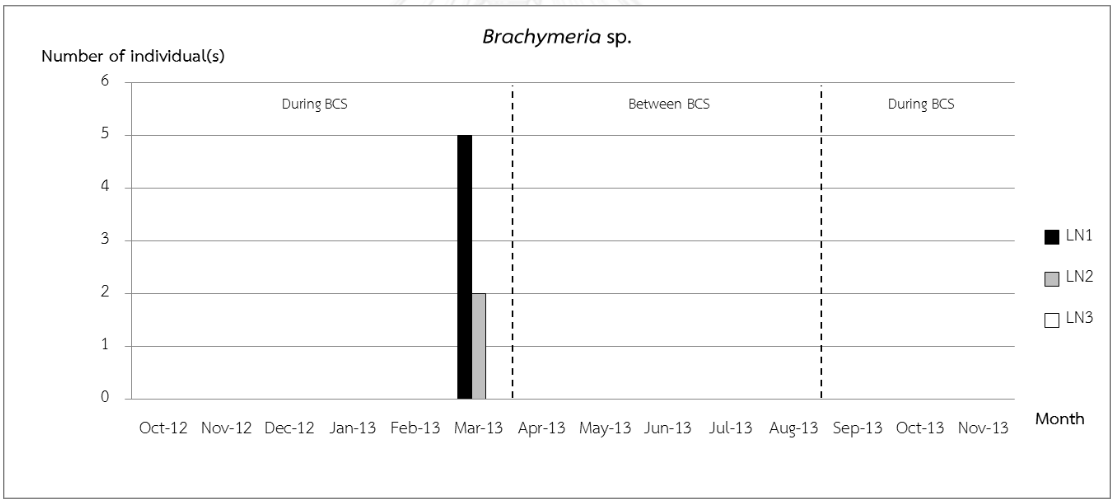

Figure 4-36 Number of *Brachymeria* sp. emerged from *P. rapae* during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

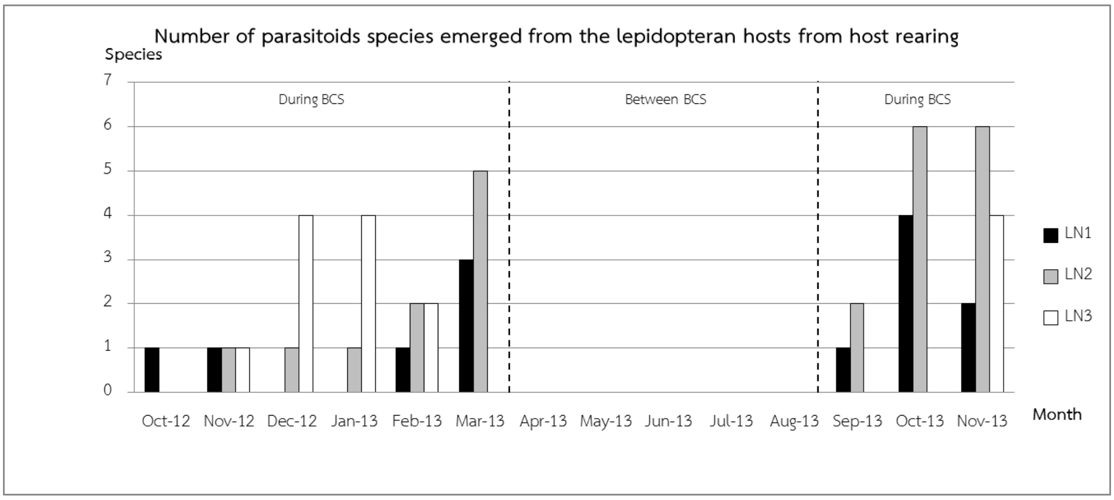

Figure 4-37 Number of parasitoids species emerged from the lepidopteran hosts rearing during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

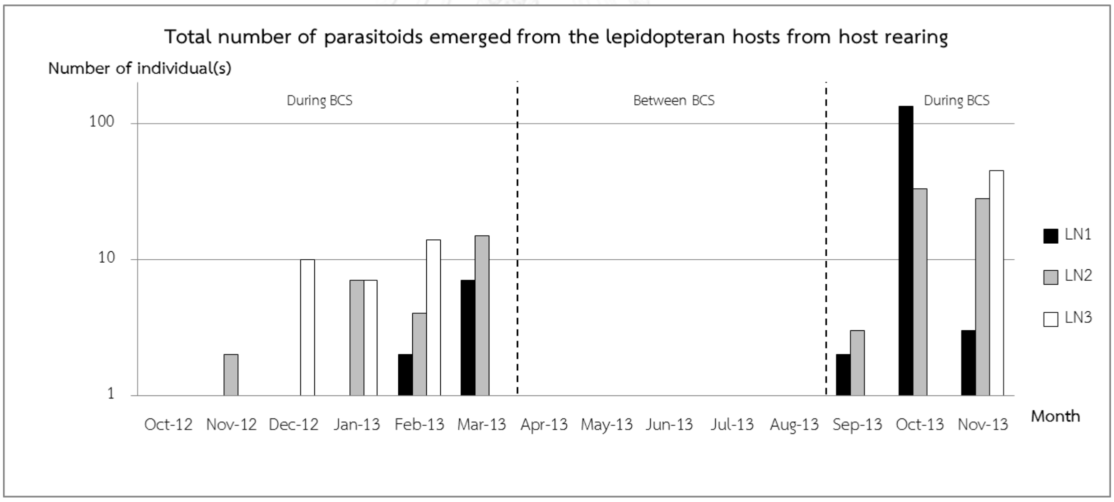

Figure 4-38 Total number of beneficial parasitoids emerged from the lepidopteran hosts rearing during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

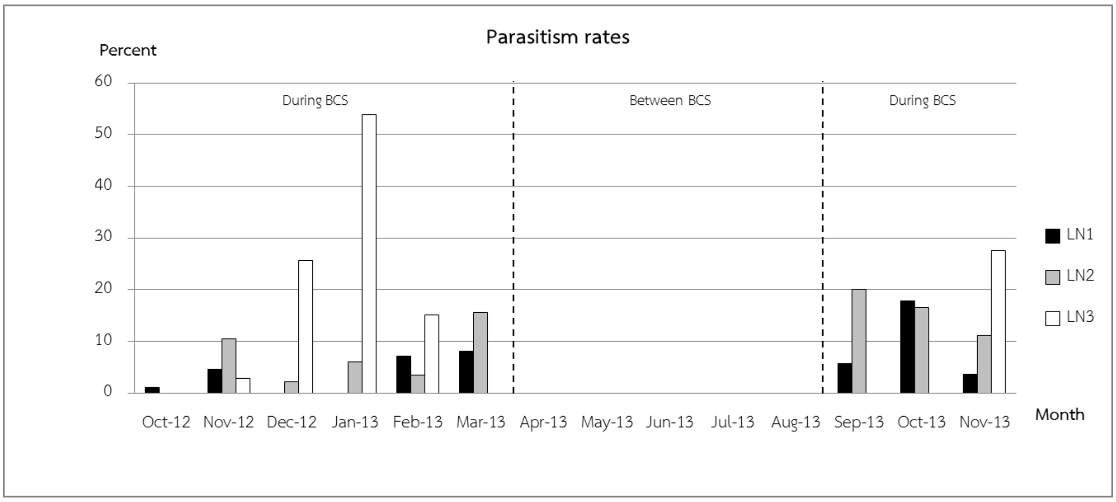

Figure 4-39 Parasitism rates of beneficial parasitoids during *Brassica* cultivated seasons (BCS) (October 2012 - March 2013 and September - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.4.1 Parasitoids of *S. litura*

Five species of parasitic wasps; *Microplitis* sp., (Hymenoptera: Braconidae) (Figure 4-40 A, B, C, and D), *Mesochorus* sp. (Hymenoptera: Ichneumonidae) (Figure 4-40 E and F), *Diadegma* sp. (Hymenoptera: Ichneumonidae) (Figure 4-40 A and B), *Charops* sp. (Hymenoptera: Ichneumonidae) (Figure 4-41 C and D), *Metopius* sp. (Hymenoptera: Ichneumonidae) (Figure 4-42 A and B), and only a species of parasitic fly; tachinid fly (Diptera: Tachinidae) (Figure 4-42 C and D) were recorded from the *S. litura*. *Microplitis* sp. was the dominant primary parasitoids of *S. litura,* the number of individuals varied from 2-147 individuals recorded from the host rearing during *Brassica* cultivated seasons. In October 2013, the number of *Microplitis* sp. had the highest successful parasitized rate with 18.9% (147 from the 779 individuals of the *S. litura*), (Tables 4-4, 4-5, 4-6). *Mesochorus* sp. was the hyperparasitoids of *Microplitis* sp.. Therefore, number of *Mesochorus* sp. recorded from the host-rearing was high when the number of *Microplitis* sp. was high. Others parasitoids of *S. litura* recorded from the host rearing were low, with low parasitism rates. The larval-pupal parasitoids, *Metopius* sp. was found only a single specimen in December 2012. *Charops* sp. were found in October 2013 (5 individuals) and November 2013 (2 individuals), respectively. *Diadegma* sp. was collected in October 2013, the same month with the highest abundance of their host. Gregarious ectoparasitoids, tachinid flies, were also found but with low rates of parasitism in December 2012, October 2013 and November 2013 with only an individual each month, respectively. Unknown ectoparasitoids (could be a eulophid wasp) has been recorded with unsuccessful parasitism in October 2013 (Figure 4-43).

Six parasitoids of *S. litura* found in this study were similar to the list of world review natural enemies of *S. litura* by Rao et al., 1992. The abundance of the beneficial parasitoids correlated to their lepidopteran host abundance. The varieties of *Brassica* cultivars were positively correlated to the number of *Microplitis* sp. (Spearman correlation; $r_S=0.825$, $p=0.002$). The lepidopteran hosts were positively correlated to their parasitoid abundance, *Microplitis* sp. ($r_S=0.954$, $p<0.001$) and *Charops* sp. ($r_S=0.730$, $p=0.020$). The abundance of hyperparasitoids, *Mesochorus* sp. was positively correlated to the total number of host rearing parasitoids ($r_S=0.836$, $p=0.002$) and parasitism rate ($r_S=0.894$, $p<0.001$) (Figure 4-44).

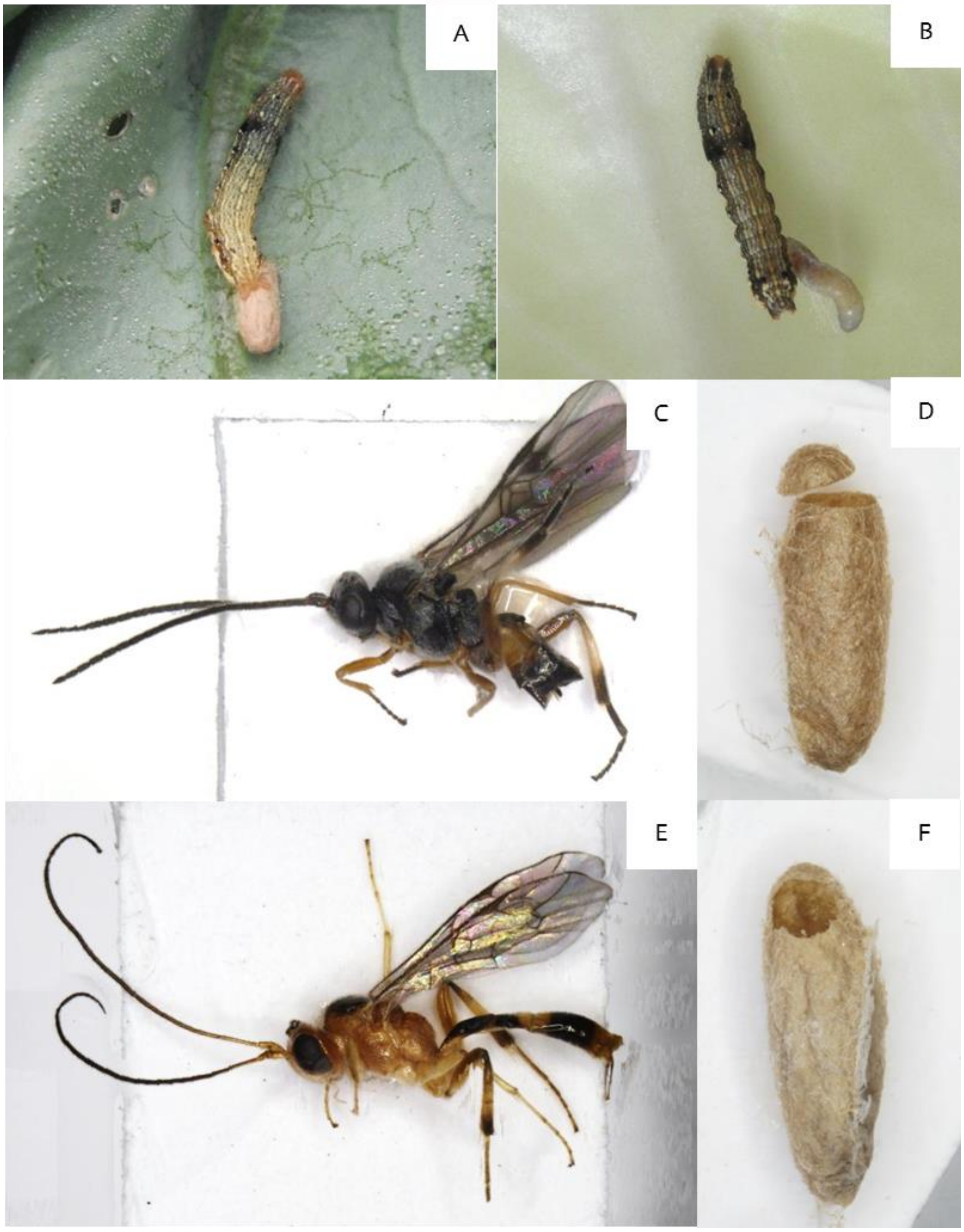

Figure 4-40 A, larva of *S. litura* and their associated parasitoid cocoon in the field observation; B, a parasitoid larva emerged from the posterior end of the host larva; C, *Microplitis* sp.; D, exuviae of *Microplitis* sp.; E, *Mesochorus* sp. and F, exuviae of *Mesochorus* sp. with different position of the emergence hole

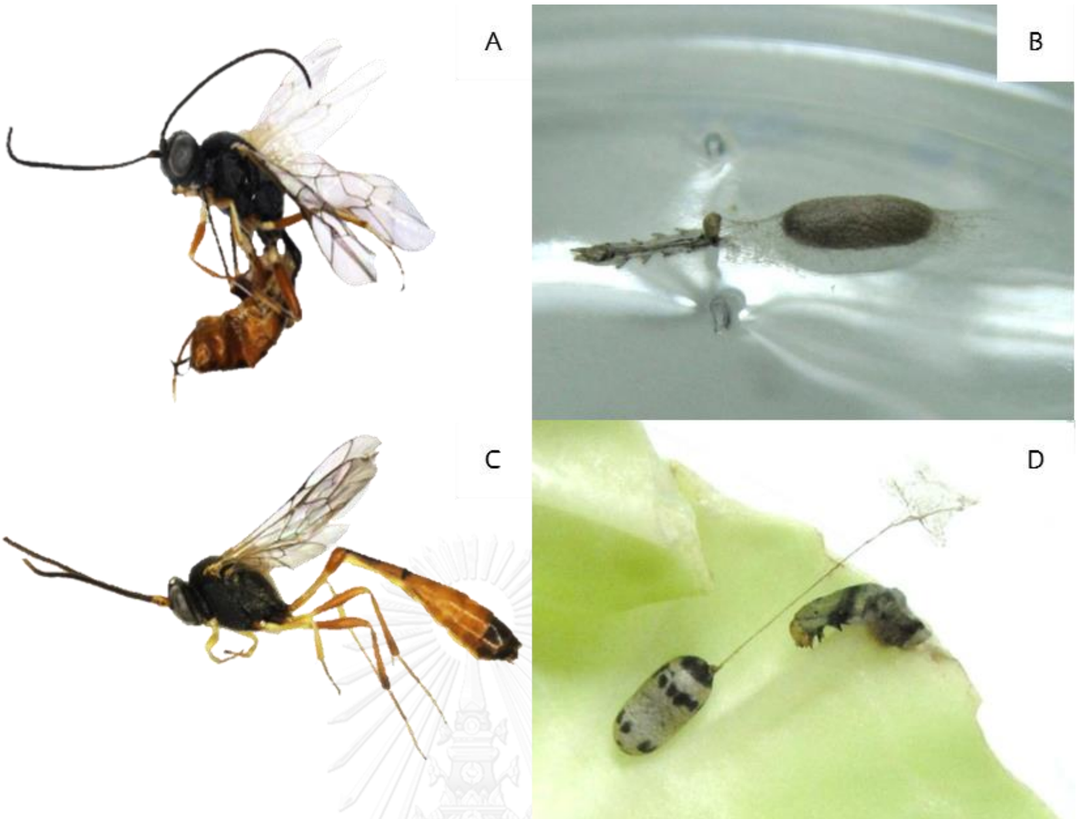

Figure 4-41 A, *Diadegma* sp.; B, pupa of *Diadegma* sp.; C, *Charops* sp. and D, pupa of *Charops* sp. and its host carcass

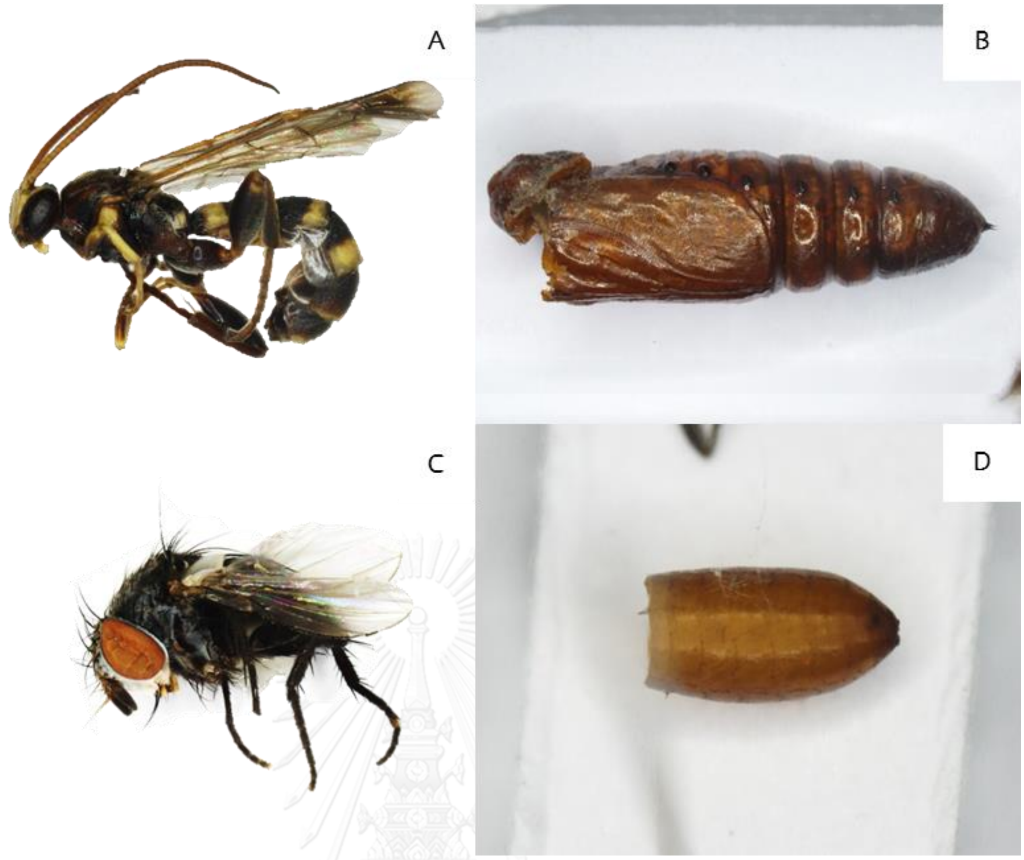

Figure 4-42 A, *Metopius* sp. larval-pupal parasitoids of *S. litura*; B, pupa cocoon of *S. litura* with the emergence hole by *Metopius* sp.; C, ectoparasitoid, tachinid fly and D, pupa case of tachinid fly

Figure 4-43 Eulophid wasp larvae attacked *S. litura*

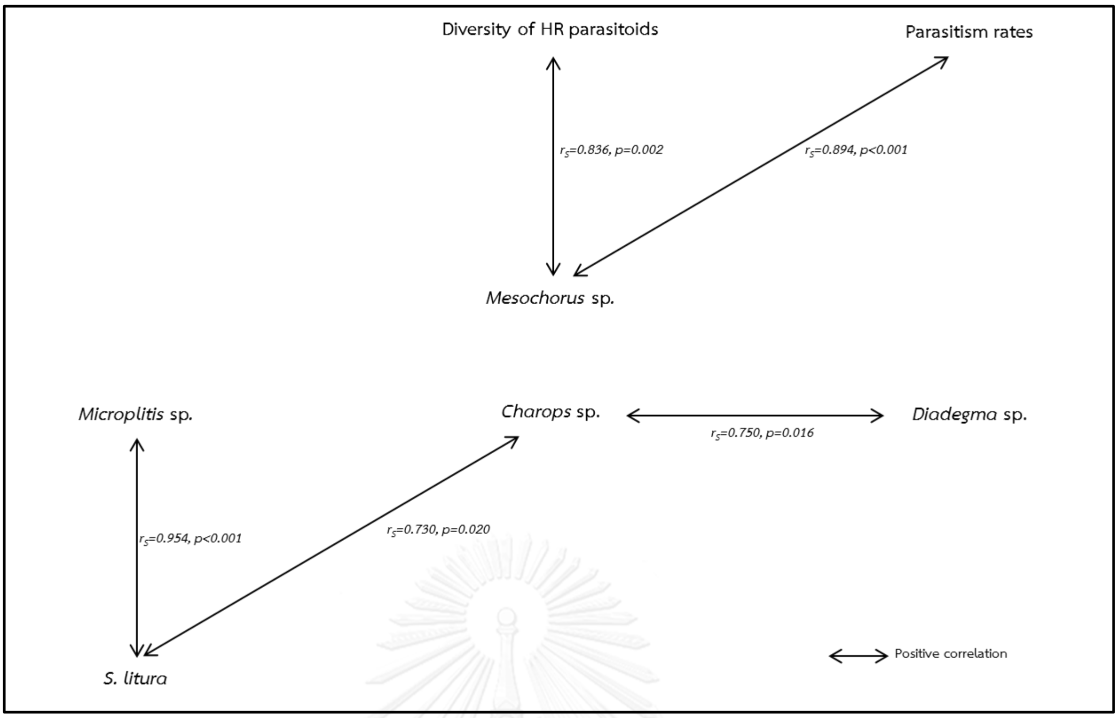

Figure 4-44 Spearman correlation of the lepidopteran host *S. litura* and their associated parasitoids; *Microplitis* sp., *Mesochorus* sp., *Charops* sp., *Diadegma* sp. and tachinid fly during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

4.4.2 Parasitoids of *P. xylostella*

Cotesia sp. (Hymenoptera; Braconidae) (Figure 4-45 A and B) was a parasitoid of the diamondback moth, *P. xylostella*. Parasitism rates of *Cotesia* sp. at the study sites were 10.2% and 4.8% in February and March 2013, respectively (Table 4-5). However, there was no significant correlation of the *Cotesia* sp. and their host abundance in this locality (Spearman correlation; $r_S=0.507, p=0.153$).

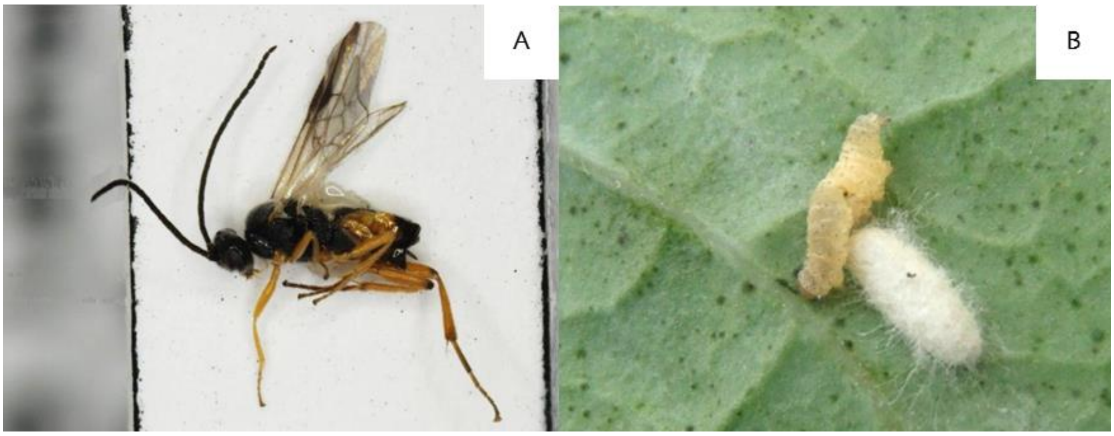

Figure 4-45 A, *Cotesia* sp.; B, pupa of *Cotesia* sp. and its host, *P. xylostella*

4.4.3 Parasitoids of *P. rapae*

The small cabbage butterfly, *P. rapae*, was parasitized by the larval-pupual parasitoids, the chalcid wasp, *Brachymeria* sp. (Hymenoptera, Chalcididae) (Figure 4-46). There were seven individuals of *Brachymeria* sp. collected from 91 individuals of *P. rapae,* with 7.7% parasitism rate in March 2013 (Table 4-5). The correlation test between host and parasitoid interactions showed that the abundance of *Brachymeria* sp. had no significant correlation with *P. rapae* abundance ($r_S=0.572, p=0.099$). Additionally, there was one record of other parasitoid on *P. rapae*, unsuccessful parasitism in February 2013 (Figure 4-47).

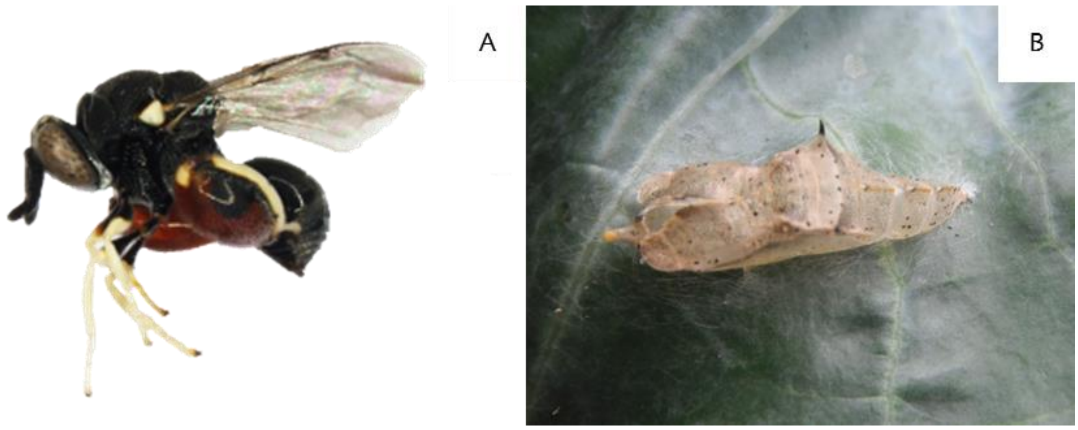

Figure 4-46 A, *Brachymeria* sp.; B, the exuviae of *P. rapae* after the *Brachymeria* sp. emerged

Figure 4-47 Unknown braconid wasps attacked *P. rapae*

4.4.4 Parasitoids of *H. undalis*

The ichneumonid wasp, *Trathala* sp. (Hymenoptera: Ichneumonidae) (Figure 4-48 A and B) was a parasitoid of *H. undalis*. The parasitism rates of *Trathala* sp. on *H. undalis* were 12.5%, 36.4% and 39.1% in January, February and March 2013, respectively (Table 4-5). Additionally, the abundance of *H. undalis* was positively correlated to the number of *Trathala* sp. on the host rearing ($r_S=0.824, p=0.004$).

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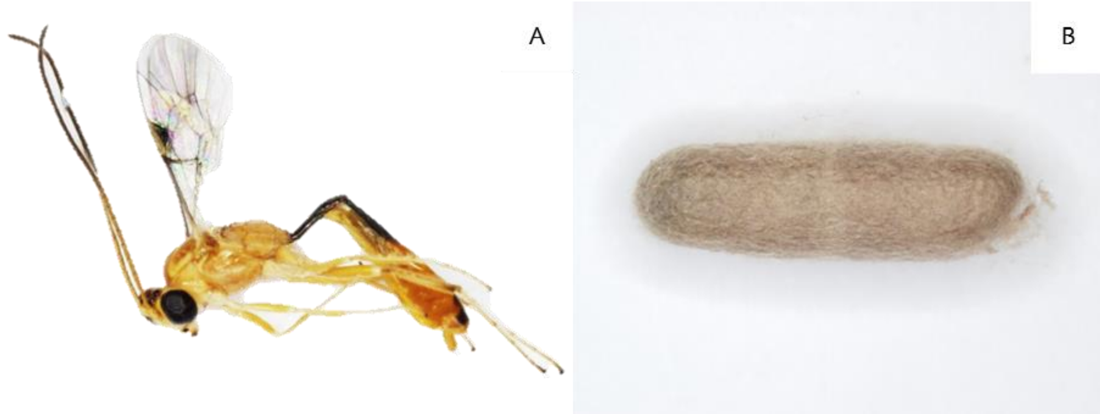

Figure 4-48 A, *Trathala* sp.; B, pupa cocoon

4.4.5 Parasitoids of *C. pavonana*

Three parasitoids species of *C. pavonana* were recorded from *Brassica* agricultural areas at the study sites. *Therophilus* sp. (Hymenoptera: Braconidae), (Figure 4-49 A and B) was the dominant parasitoid of the *C. pavonana*. *Crocidolomia pavonana* normally live together in a cluster or a mass on the plants which provide parasitoids opportunity to parasitize. The parasitism rates of *Therophilus* sp. were 100%, 15.1% and 12.9% in January, October and November 2013, respectively (Table 4-5, 4.6). The gregarious endoparasitoid, *Dolichogenidae* sp. (Hymenoptera: braconidae) (Figure 4-49 C, D and E) had 4.1% of parasitism rate in October 2013. Lastly, *Chelonus* sp. (Hymenoptera: Braconidae) (Figure 4-49 F) was found only a single specimen in November 2013 (Table 4-5).

The abundance of *C. pavonana* was positively correlated to the abundance of *Dolichogenidae* sp. ($r_S=0.779$, $p=0.009$) and *Therophilus* sp. ($r_S=0.888$, $p<0.001$). Number of *Dolichogenidae* sp. was positively correlated to the number of *Therophilus* sp. ($r_S=0.841$, $p=0.002$). Also, the abundance of *Dolichogenidae* sp. was positively correlated to the total number of host rearing parasitoid species, the total number of host rearing parasitoids and parasitism rates (($r_S=0.731$, $p=0.020$), ($r_S=0.730$, $p=0.0200$), and ($r_S=0.730$, $p=0.0200$), respectively). Lastly, number of *Therophilus* sp.

was positively correlated to the total number of host rearing parasitoids and parasitism rates ((r_S=0.740, p=0.00), and (r_S=0.683, p=0.036), respectively) (Figure 4-50).

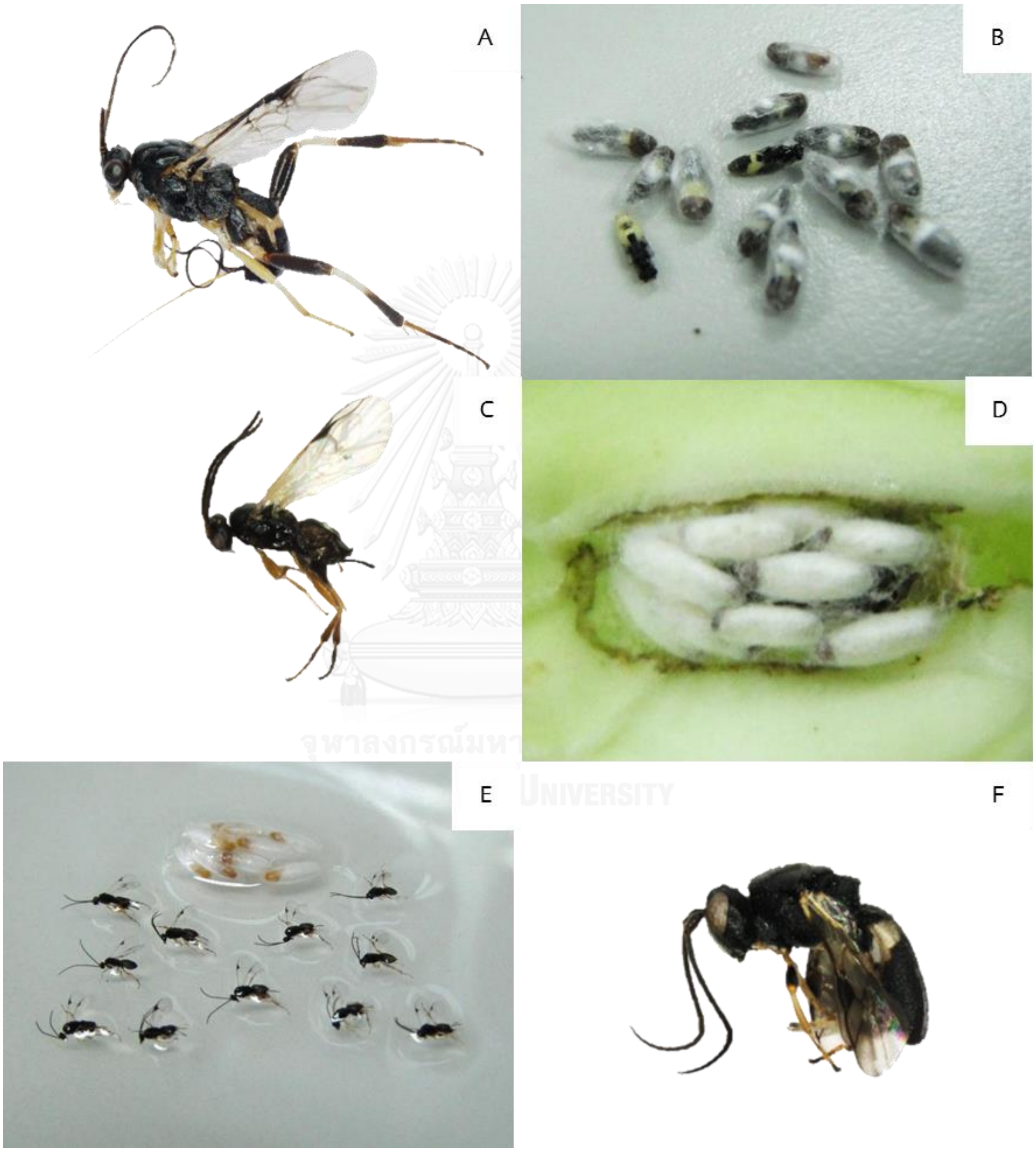

Figure 4-49 A, *Therophilus* sp.; B, pupae of *Therophilus* sp.; C, *Dolichogenidae* sp.; D, pupae of *Dolichogenidae* sp.; E, the gregarious parasitoids, eleven individuals of *Dolichogenidae* sp. emerged from a single host and F, *Chelonus* sp.

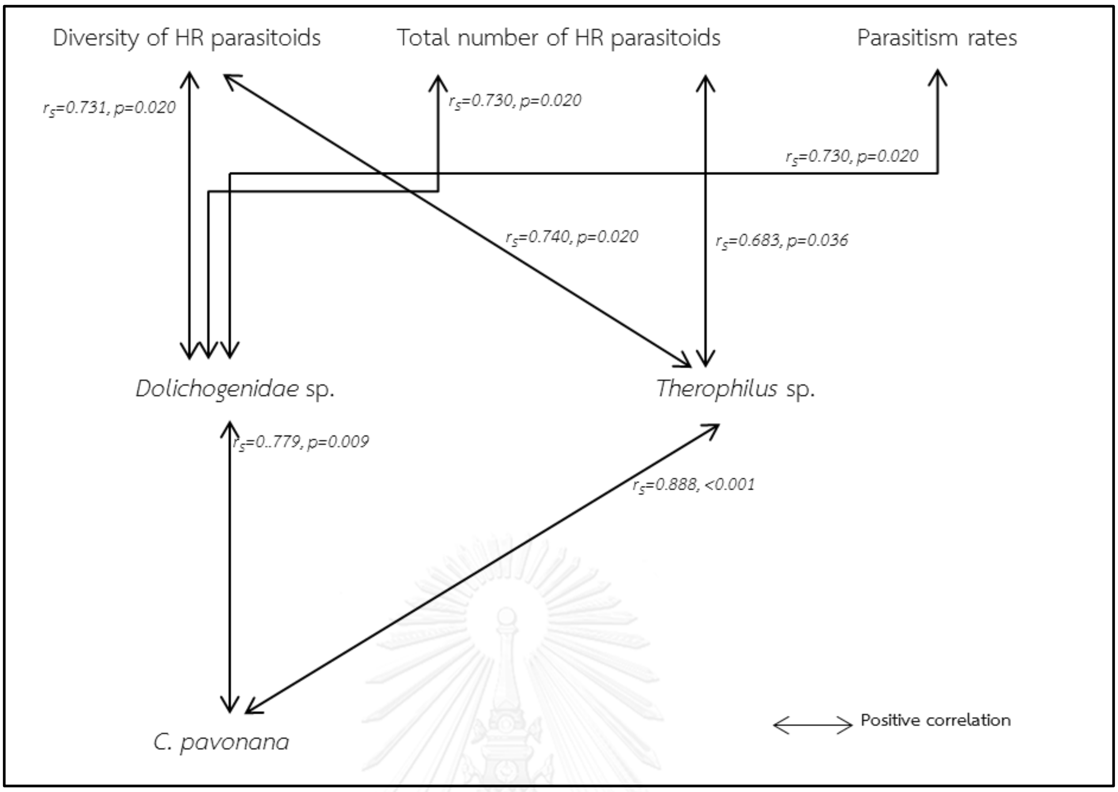

Figure 4-50 Spearman correlations of the lepidopteran host, *C. pavonana* and their associated parasitoids; *Dolichogenidae* sp. and *Therophilus* sp. during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

4.4.6 Parasitoids of *T. ni*

The cabbage looper, *T. ni,* had been parasitized by two species of their associated parasitoids, *Snellius* sp. (Hymenoptera: Braconidae), (Figure 4-51 A) and *Cotesia* sp. (Hymenoptera: Braconidae) (Figure 4-51 B and C), both of them parasitized *T. ni* with only an individual recorded. *Cotesia sp.* was the gregarious parasitoids on *T. ni* in September 2013 and the solitary parasitoid, *Snellius* sp., parasitized *T. ni* in October 2013 (Table 4-4). However, there was no significantly correlation between *T. ni* and *Cotesia* sp. (r_S*=0.554, p=0.111*) and between *T. ni* and *Snellius* sp. (r_S*=-0.411, p=0.234*).

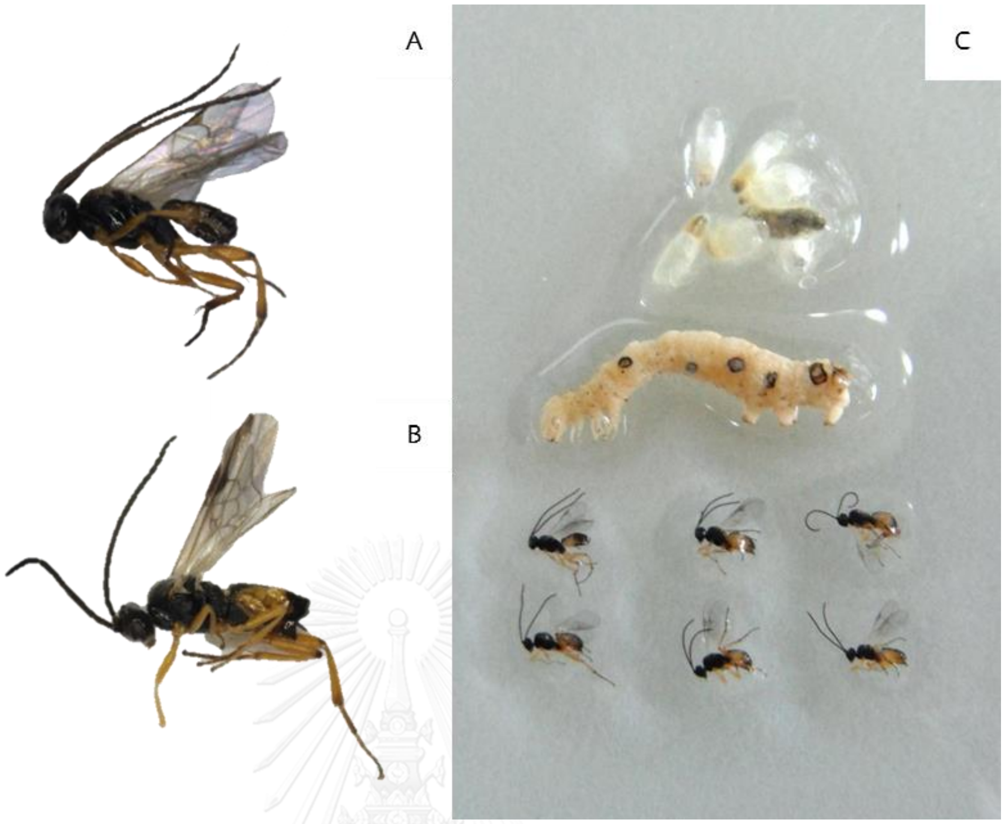

Figure 4-51A, the solitary parasitoids *Snellius* sp.; B, the gregarious parasitoids, *Cotesia* sp.; C, six individuals of *Cotesia* sp. emerged from an individual of *T. ni*

4.4.7 Parasitoids of *O. subnotata*

Ovassca subnotata was parasitized successful by the cryptinid wasps (Hymenoptera: Braconidae) (Figure 4-52 A and B) in November 2013 (Table 4-6). In the same month, it was attacked by the unknown gregarious parasitoids with unsuccessful parasitism in the same month (Figure 4-53). However, there was no significantly correlated between *O. subnotata* and cryptinid wasp (r_S=*0.286, p=0.434*).

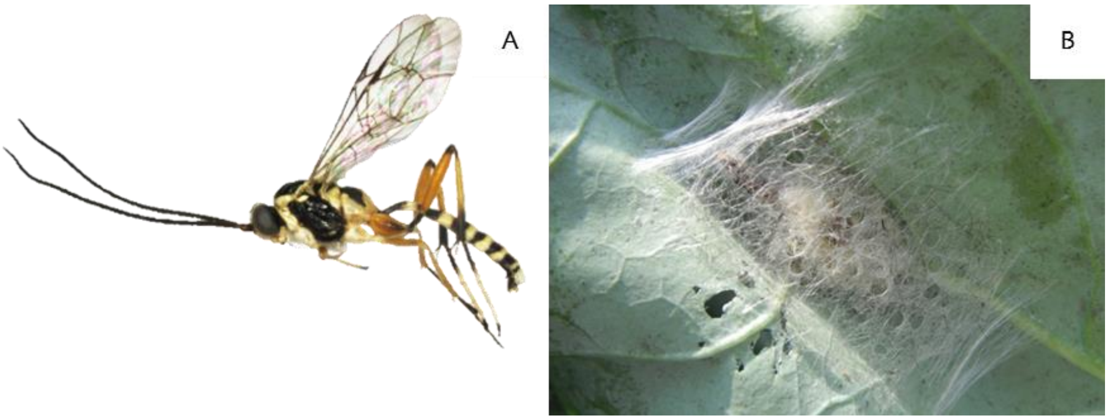

Figure 4-52 A, cryptinid wasps; B, pupa of *O. subnotata*

Figure 4-53 unknown parasitoids of *O. subnotata*

4.4.8 Diversity of parasitoids from host rearing

The highest number of the lepidopteran pests was found in October 2013 with 955 individuals of the larvae and pupae, and the highest numbers of beneficial parasitoids, 195 individuals, was also found in the same month. However, the most diverse parasitoids were recorded in March 2013 with 1.36 and 0.30 of Shannon-Weiner and Simpson indices, respectively (Table 4-6). Diversity of parasitoids from host rearing was positively correlated with the diversity and total number of the lepidopteran pests, ((r_S=*0.716, p=0.025*), (r_S=*0.720, p=0.025*)). Total number of parasitoids from host rearing were positively correlated to the diversity of the lepidopteran pests (r_S=*0.787, p<0.001*) and total number of the lepidopteran pests (r_S=*0.950, p<0.001*), respectively. Moreover, diversity and total number of parasitoids was positively correlated (r_S=*0.881, p<0.001*), and also positively correlated to parasitism rates r_S=*0.949, p<0.001* and r_S=*0.800, p=0.006*, respectively (Figure 4-54).

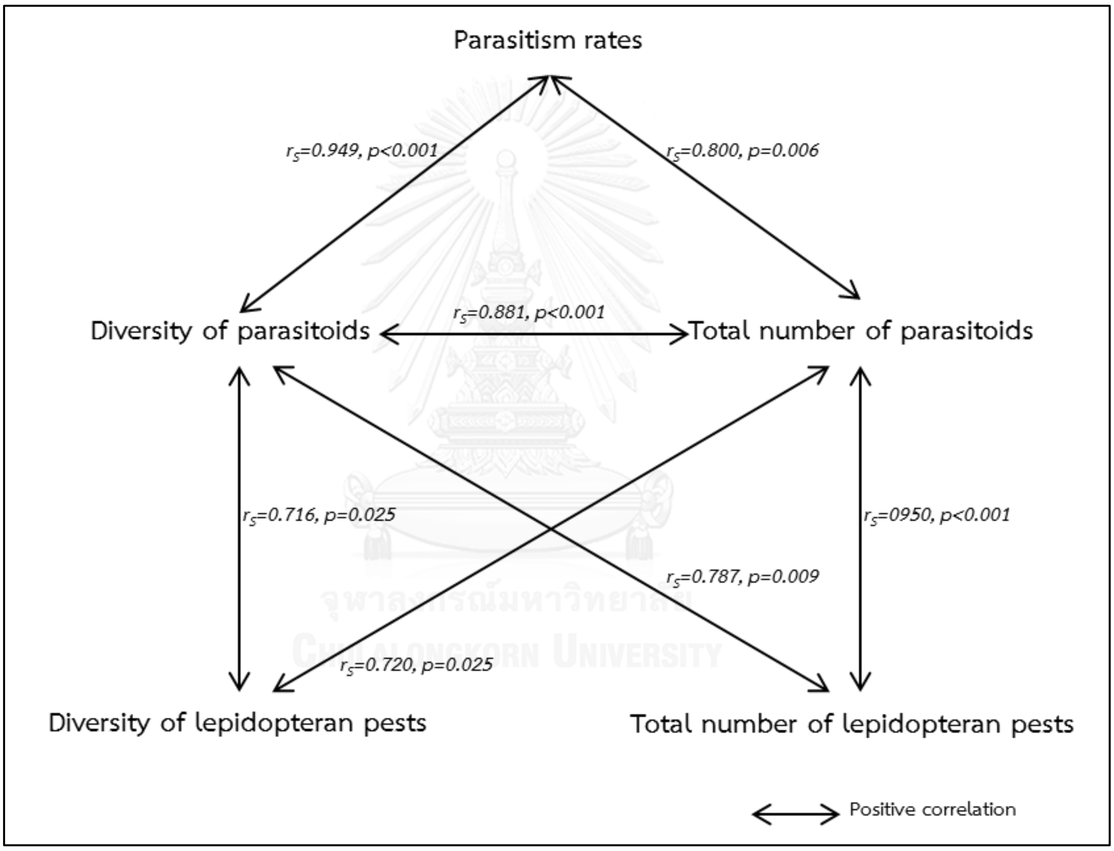

Figure 4-54 Spearman correlations of lepidopteran pests, parasitoids from host rearing and parasitism rates during *Brassica* cultivated seasons (October 2012 - March 2013 and September - November 2013)

4.5 Abundance of beneficial parasitic wasps

Thirteen species of beneficial parasitic wasps were collected from host rearing (*Microplitis* sp., *Mesochorus* sp., *Diadegma* sp., *Charops* sp., *Metopius* sp., *Dolichogenidae* sp., *Therophilus* sp., *Chelonus* sp., *Cotesia* spp., *Snellius* sp., *Trathala* sp., cryptinid wasp and *Brachymeria* sp.). The abundance of parasitoids during and between *Brassica* cultivated seasons (October 2012 - November 2013) were recorded by four sampling methods (Malaise traps, mobile bucket light traps, yellow pan traps and aerial net). Total number of each beneficial parasitoid species on trap sampling were compared among the three study site and during/between *Brassica* cultivated seasons (Table 4-7).

Table 4-7 Abundance of beneficial parasitic wasps (four trap samplings) collected from *Brassica* crops in the three study sites (LN1, LN2 and LN3) at Lainan Subdistrict, Wiang Sa District, Nan Province (October 2012 - November 2013)

No.	Parasitoid	Study site			Kruskall-Wallis		
		LN1	LN2	LN3	*H*	*df*	*p*
1	*Microplitis* sp.	/	/	/	3.569	2	0.168
2	*Mesochorus* sp.	/	/	/	1.250	2	0.535
3	*Charops* sp.	/	/	/	3.508	2	0.173
4	*Diadegma* spp.	/	/	/	4.352	2	0.114
5	*Metopius* sp.	/	/	/	2.969	2	0.227
6	*Therophilus* sp.	/	/	/	0.880	2	0.644
7	*Dolichogenidaea* sp.	/		/	5.023	2	0.081
8	*Chelonus* sp.	/	/	/	2.523	2	0.283
9	*Cotesia* spp.	/	/	/	4.052	2	0.132
10	*Snellius* sp.	/	/	/	1.319	2	0.517
11	*Trathala* sp.	/		/	1.601	2	0.449
12	cryptinid wasp	/	/	/	5.334	2	0.069
13	*Brachymeria* sp.	/	/	/	0.589	2	0.745

4.5.1 Abundance of *Microplitis* sp.

The highest number of individuals of *Microplitis* sp. (36 individuals) was recorded from the LN3 in September 2013 (during *Brassica* cultivated season), while the lowest individuals of *Microplitis* sp. was found between *Brassica* cultivated season (Figure 4-55). However, there was no significantly different on the abundance of *Microplitis* sp. among the three study sites (Kruskal-Wallis; *H=3.569, df=2, p=0.168*), and there was no significant difference of *Microplitis* sp. abundance collected from the trap sampling methods during and between *Brassica* cultivated seasons (t-test; *t=1.32, df=12, p=0.213*) (Figure 4-56).

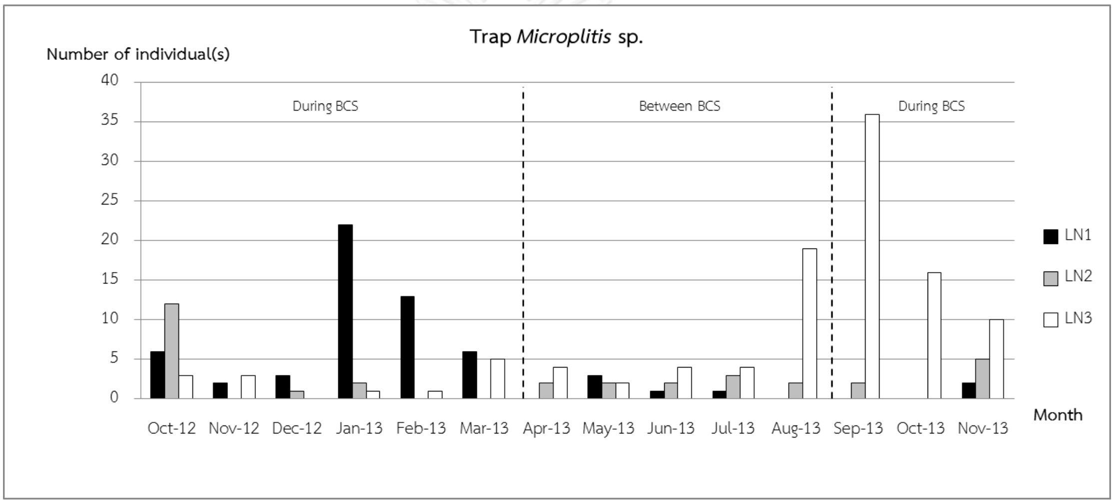

Figure 4-55 Abundance of *Microplitis* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

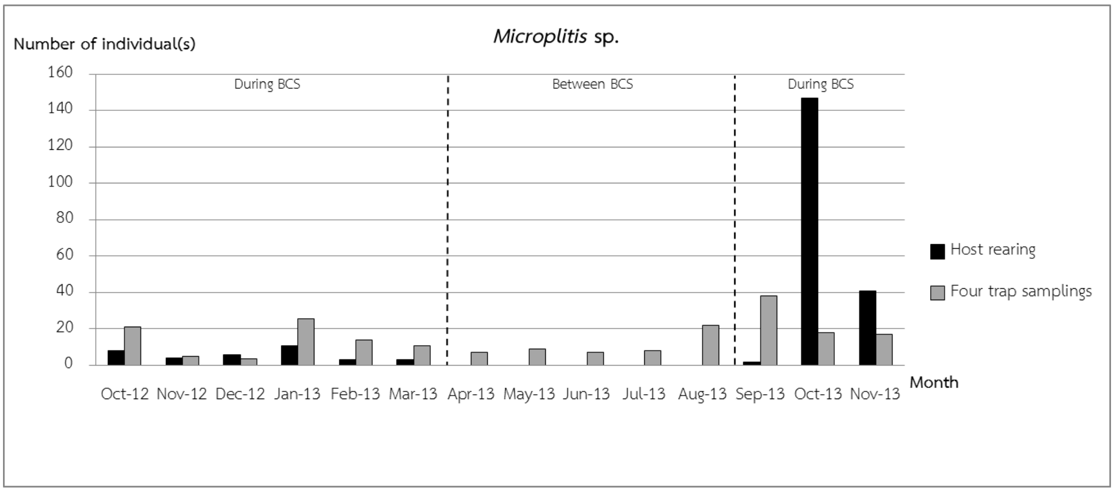

Figure 4-56 Number of *Microplitis* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.2 Abundance of *Mesochorus* sp.

The hyperparasitoid, *Mesochorus* sp. was usually found during *Brassica* cultivated seasons; except for June 2013, a single individual had been collected from the trap sampling between the cultivated seasons. There was no significant difference of *Mesochorus* sp. among the three study sites (Kruskall-Wallis; *H=1.250, df=2, p=0.535*) (Figure 4-57). Abundance of *Mesochorus* sp. from host rearing was higher than the trap sampling in December 2012, January 2013, March 2013, October 2013 and November 2013 (Figure 4-58). Abundance of *Mesochorus* sp. during and between *Brassica* cultivated seasons was not significantly different on the number of *Mesochorus* sp. (*Mann-Whitney U Statistic=15.000, T=30.00, p=0.276*).

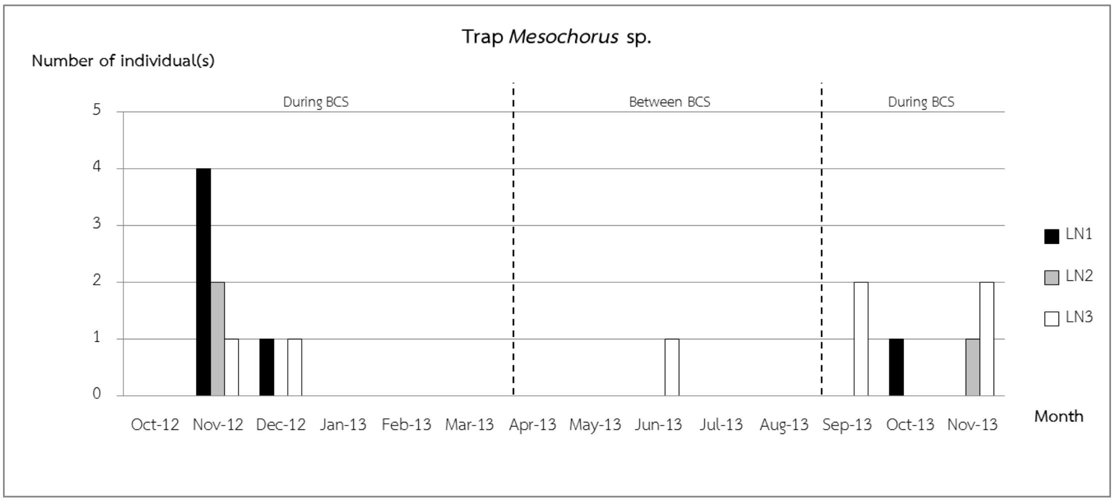

Figure 4-57 Abundance of *Mesochorus* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

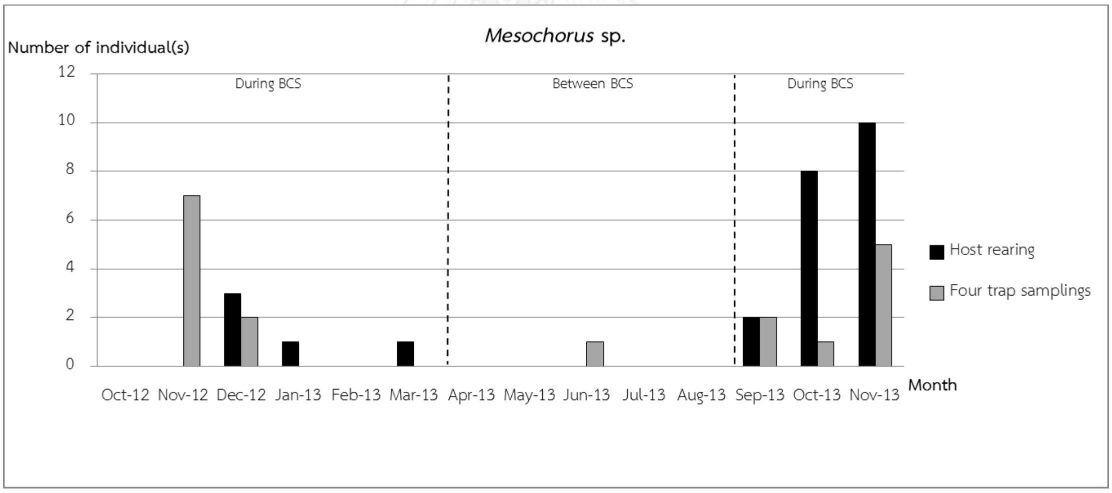

Figure 4-58 Number of *Mesochorus* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.3 Abundance of *Diadegma* sp.

The highest abundance of *Diadegma* sp. was found at the LN3 site, 31 individuals were collected in October 2013 (Figure 4-59). The Kruskall-Wallis analysis showed that there was no significant difference of the *Diadegma* sp. abundance among the three study sites (*H=4.352, df=2, p=0.114*). Only a single specimen of *Diadegma* sp. had been recorded from the host rearing. However, in the trap sampling methods, *Diadegma* sp. had been found every month, with no significant difference of *Diadegma* sp. during and between *Brassica* cultivated seasons (*Mann-Whitney U statistic=14.500, T=29.500, p=0.312*) (Figure 4-60). Although there was no significant difference between *Brassica* cultivated seasons, the abundance of *Diadegma* sp. was positively correlated to the *Brassica* cultivation area (size) and the abundance of their host, *S. litura* (Spearman correlation; r_S*=0.633, p=0.014* and r_S*=0.678, p=0.036*, respectively) (Figure 4-61).

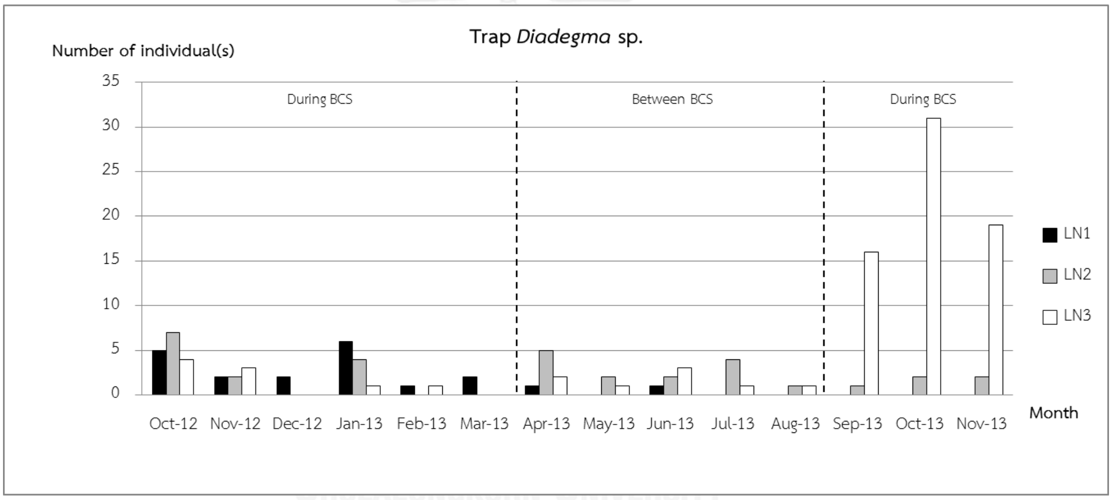

Figure 4-59 Abundance of *Diadegma* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

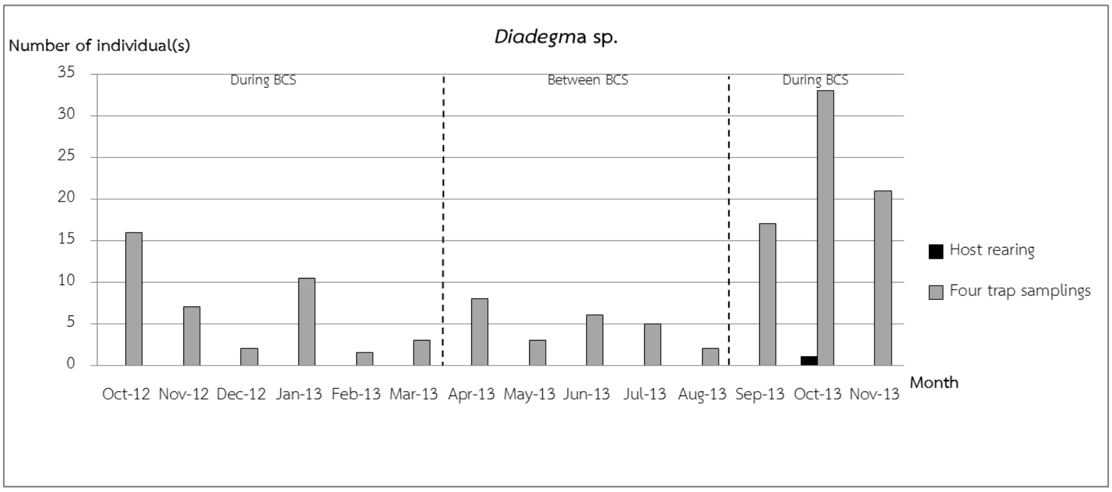

Figure 4-60 Number of *Diadegma* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

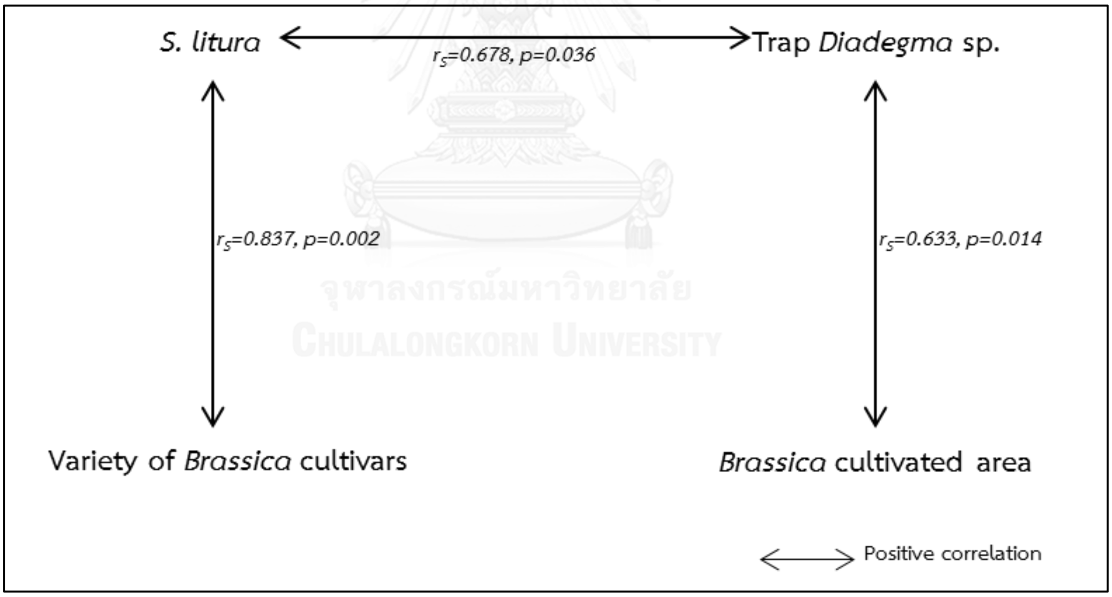

Figure 4-61 Spearman correlations between the *Brassica* cultivation area, lepidopteran hosts, *S. litura* and the number of *Diadegma* sp. collected from trap samplings during and between *Brassica* cultivated seasons (October 2012-November 2013)

4.5.4 Abundance of *Charops* sp.

Number of *Charops* sp. collected from the trap samplings was ranged from 1-4 individuals each month during and between *Brassica* cultivated seasons. There was no significant difference of the *Charops* sp. individuals among the three study sites (Kruskall-Wallis; *H=3.508, df=2, p=0.173*) (Figure 4-62). Total number of *Charops* sp. collected from the trap samplings was recorded every month, excepted for August 2013, and the number of *Charops* sp. emerged from host rearing was recorded only in October and November 2013 (Figure 4-63). The abundance of *Charops* sp. from the trap samplings was positively correlated to the varieties of *Brassica* cultivars, the *Brassica* cultivation area, and the number of *S. litura* (Spearman correlation; $r_S=0.838, p<0.001$; $r_S=0.759, p=0.001$ and $r_S=0.675, p=0.036$, respectively) (Figure 4-64). Similarly to the t-test analysis, the abundance of *Charops* sp. during and between *Brassica* cultivated seasons were significantly different, and their abundance were higher during the cultivated seasons than between the cultivated season (t-test; $t=2.788, df=12, p=0.016$).

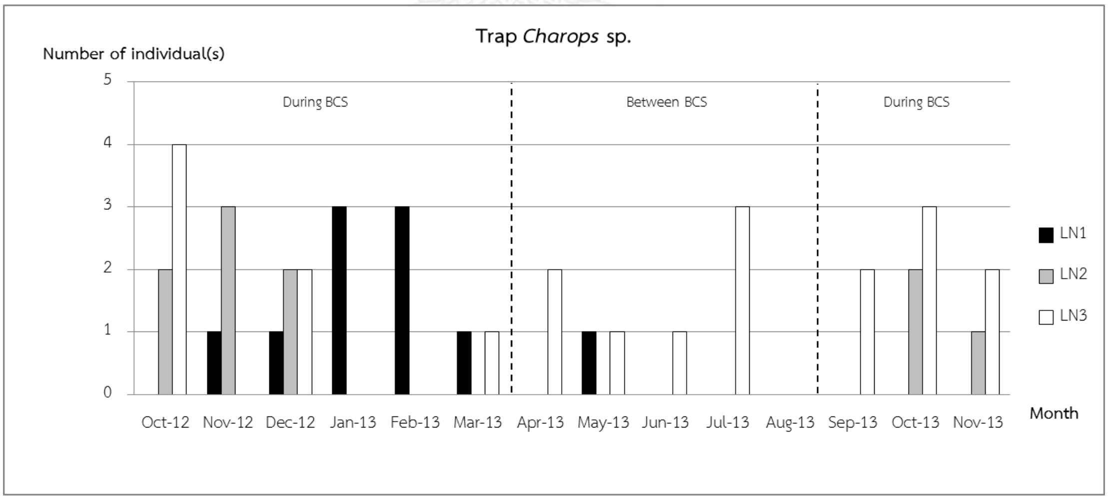

Figure 4-62 Abundance of *Charops* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

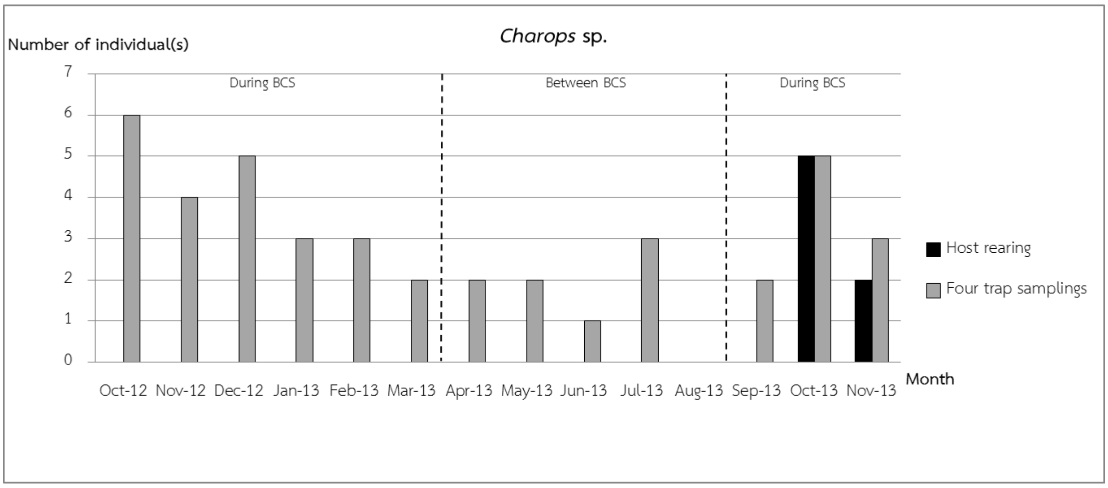

Figure 4-63 Number of *Charops* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

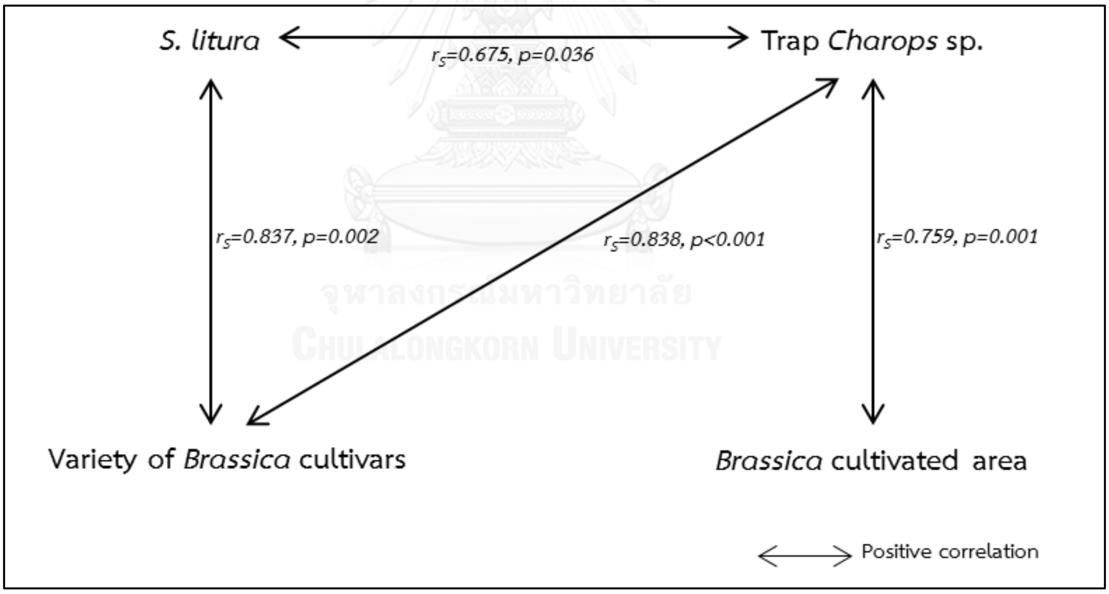

Figure 4-64 Spearman correlations between the *Brassica* cultivation area (size), varieties of *Brassica* species, lepidopteran host, *S. litura* and the number of *Charops* sp. from trap samplings during and between *Brassica* cultivated seasons (October 2012 - November 2013)

4.5.5 Abundance of *Metopius* sp.

There was no significant difference of the abundance of *Metopius* sp. among the three study sites (Kruskall-Wallis; *H=2.969, df=2, p=0.227*) (Figure 4-65). The highest numbers of *Metopius* sp. recorded from the trap samplings were 5 individuals in December 2012, the same month a single *Metopius* sp. emerged from host rearing (Figure 4-66). Lastly, there were no significant difference of *Metopius* sp. abundance during and between *Brassica* cultivated seasons (*Manwhitney U Statistic=16.000, T=31.000, p=0.387*).

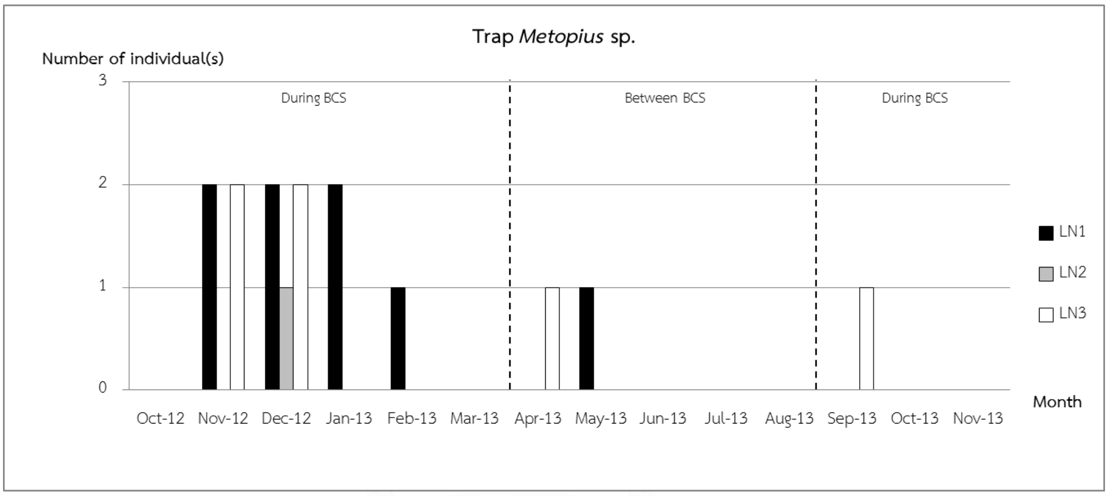

Figure 4-65 Abundance of *Metopius* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

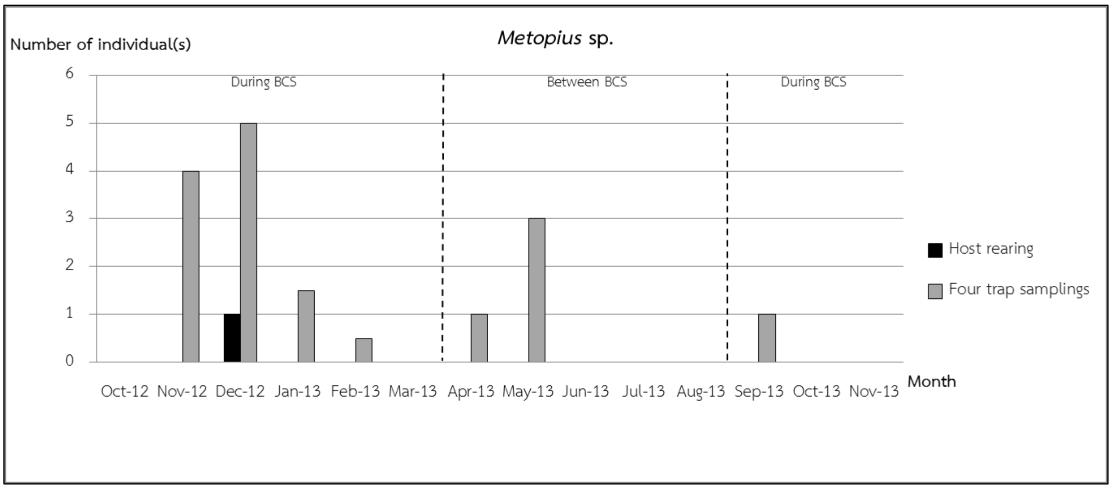

Figure 4-66 Number of *Metopius* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.6 Abundance of *Dolichogenidae* sp.

Numbers of the *Dolichogenidae* sp. collected from the trap samplings ranged from 1-52 individuals and the highest number was 52 individuals from the trap sampling at the LN2 site in May 2013. However, there was no significant difference of *Dolichogenidae* sp. collected from the trap samplings among the three study sites (Kruskall-Wallis; *H=5.023, df=2, p=0.081*) (Figure 4-67). The abundance of *Dolichogenidae* sp. from the trap samplings was recorded every month during and between *Brassica* cultivated seasons. For the host rearing methods, 27 individuals (from 3 individuals of host) of *Dolichogenidae* sp. were collected only in October 2013 (Figure 4-68). From t-test analysis, the number of *Dolichogenidae* sp. collected from the trap samplings showed no significant difference during and between *Brassica* cultivated seasons (*t-test=-0.623, df=12, p=0.545*).

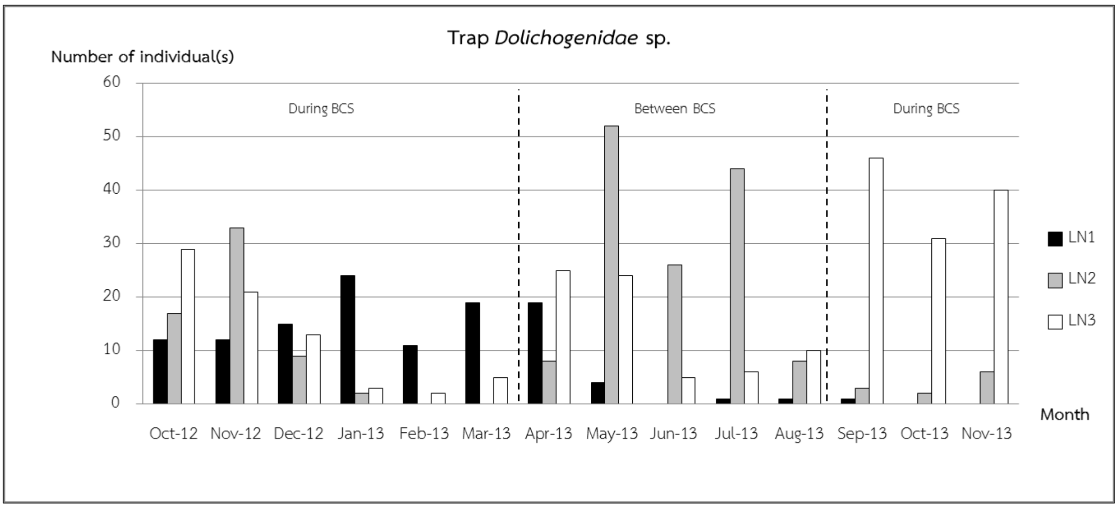

Figure 4-67 Abundance of *Dolichogenidae* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

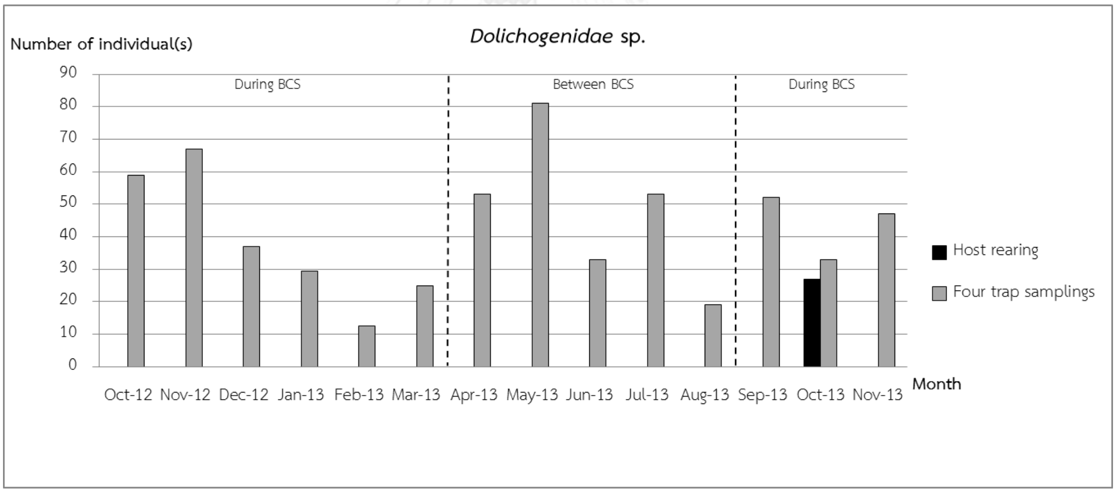

Figure 4-68 Number of *Dolichogenidae* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.7 Abundance of *Therophilus* sp.

Therophilus sp. were collected from trap sampling in December 2012 at the LN3 site and March 2013 at the LN1 site, with only a single specimen collected in those 2 months, and there was no significant difference on the number of *Therophilus* sp. collected from the trap samplings among the three study sites (Kruskall-Wallis; *H=0.880, df=2, p=0.644*) (Figure 4-69). The abundance of *Therophilus* sp. recorded from the host rearing was higher than the trap sampling with the maximum numbers of 20 individuals in November 2013 (Figure 4-70). Moreover, there was no significantly of the *Therophilus* sp. abundance from the trap sampling during and between *Brassica* cultivated seasons (Mann-Whitney U Statistic=17.500, *T=32.500, p=0.323*).

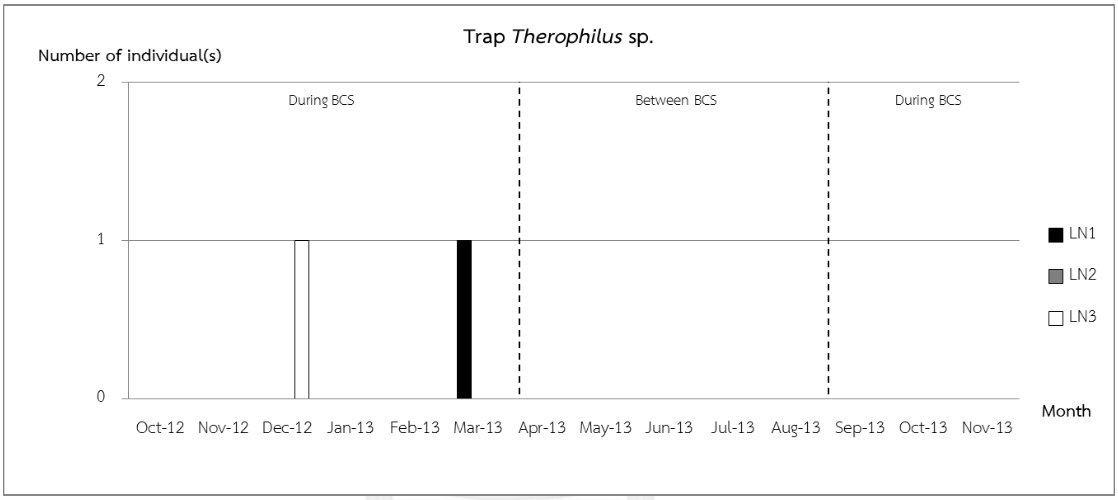

Figure 4-69 Abundance of *Therophilus* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

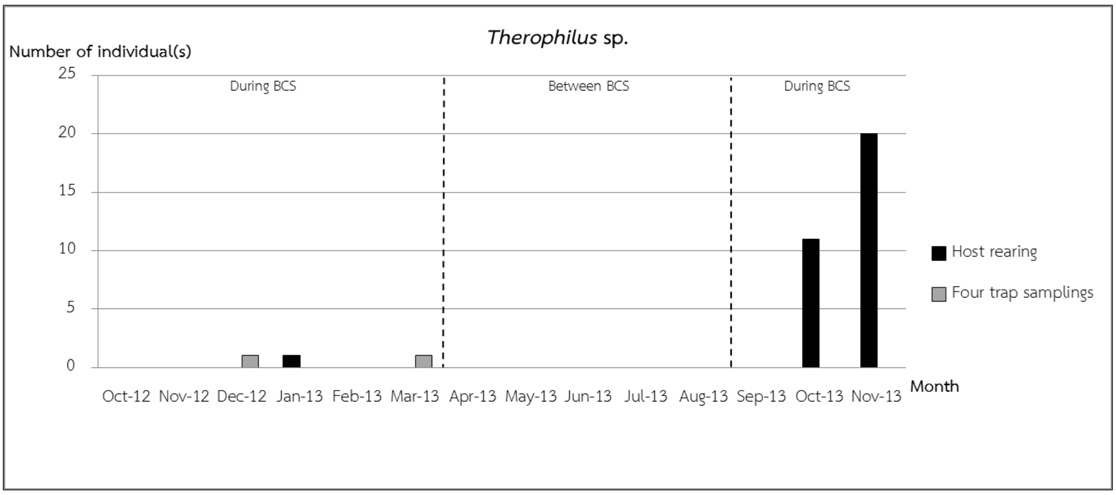

Figure 4-70 Number of *Therophilus* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.8 Abundance of *Chelonus* sp.

The maximum numbers of *Chelonus* sp., 34 individuals, had been collected at LN3 site in April 2013 and LN2 site in May 2013. There was no significant difference of the *Chelonus* sp. numbers collected from trap samplings among the threes study sites (Kruskall-Wallis; $H=2.523, df=2, p=0.283$) (Figure 4-71). From the host rearing, *Chelonus* sp. had been collected with only a single specimen in November 2013, while the number of *Chelonus* sp. collected from the trap samplings was higher between *Brassica* cultivated seasons (Figure 4-72). The number of *Chelonus* sp. recorded from the trap sampling between the cultivated season was significantly higher than number of these wasps recorded during the cultivated seasons (t-test; $t=-2.687, df=12, p=0.020$). This result was similar to the positive correlation on the average temperature and the abundance of *Chelonus* sp. collected from the trap samplings (Spearman correlation; $r_S=0.549, p=0.041$).

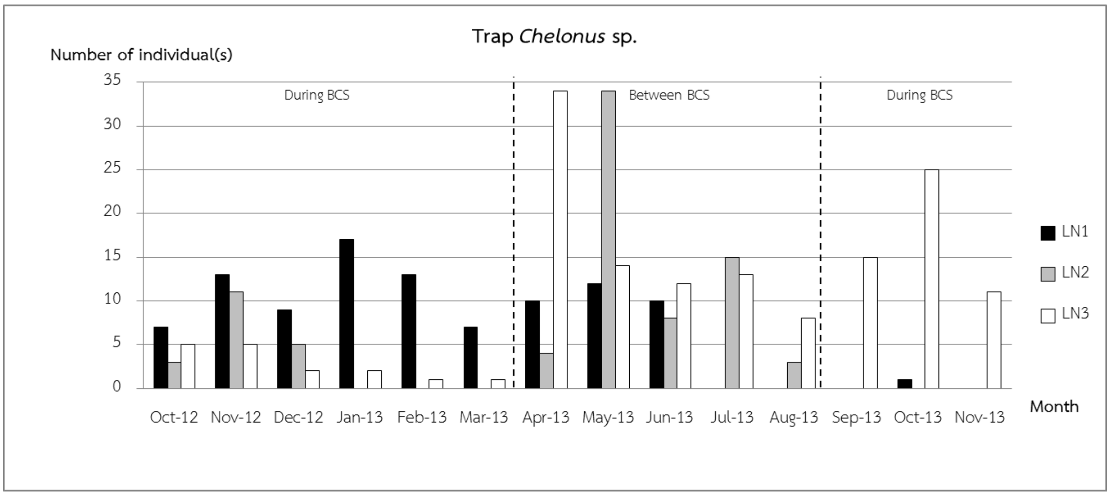

Figure 4-71 Abundance of *Chelonus* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

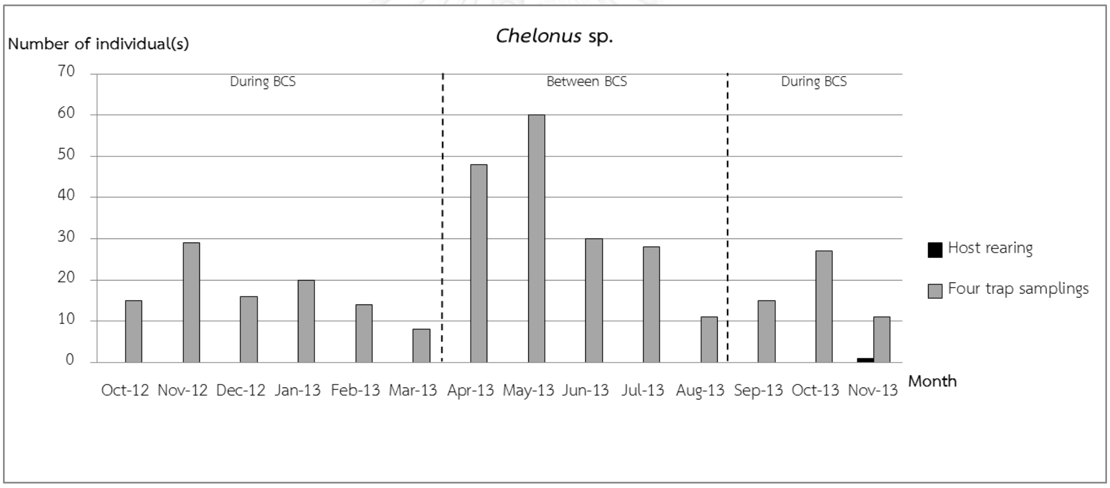

Figure 4-72 Number of *Chelonus* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.9 Abundance of *Cotesia* spp.

The highest numbers of *Cotesia* spp. recorded from the trap samplings were 36 individuals in September 2013 (Figure 4-73), and there was no significant difference of *Cotesia* spp. abundance collected from the trap samplings among the three study sites (Kruskall-Waliis; *H=4.052, df=2, p=0.132*). *Cotesia* spp. were usually recorded from the trap sampling every month, while their abundance from host rearing was recorded in February, March and October 2013 (Figure 4-74). However, there are no significantly different of the abundance of *Cotesia* spp. Recorded from the trap samplings during and between *Brassica* cultivated seasons (t-test; *t=0.643, df=12, p=0.532*).

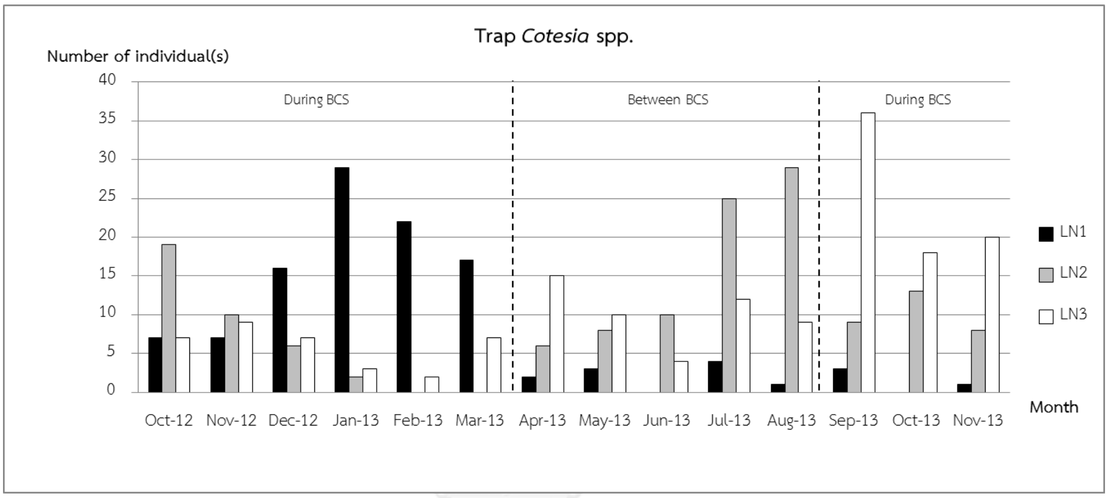

Figure 4-73 Abundance of *Cotesia* spp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

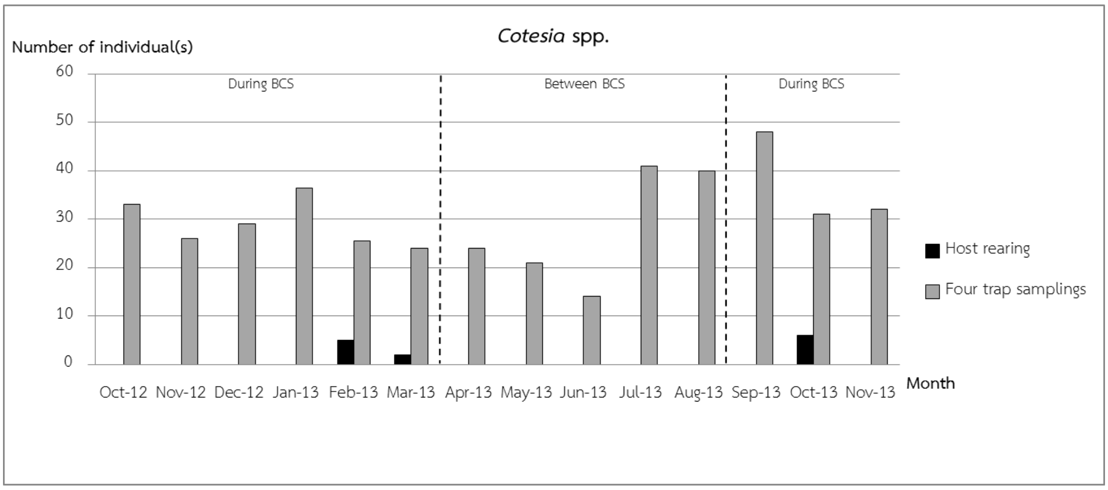

Figure 4-74 Number of *Cotesia* spp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.10 Abundance of *Snellius* sp.

Snellius sp. was collected from the trap sampling inranged of 1-3 individuals in each study site, but there was no significant difference among the study sites (Kruskall-Wallis; *H=1.319, df=2, p=0.517*) (Figure 4-75). Also, there was no significant difference of *Snellius* sp. abundance during and between *Brassica* cultivated seasons (Mann-Whitney U Statistic=13.500, *T=28.500, p=0.227*) (Figure 4-76). However, only a single specimen of *Snellius* sp. were recorded from host rearing in September 2013.

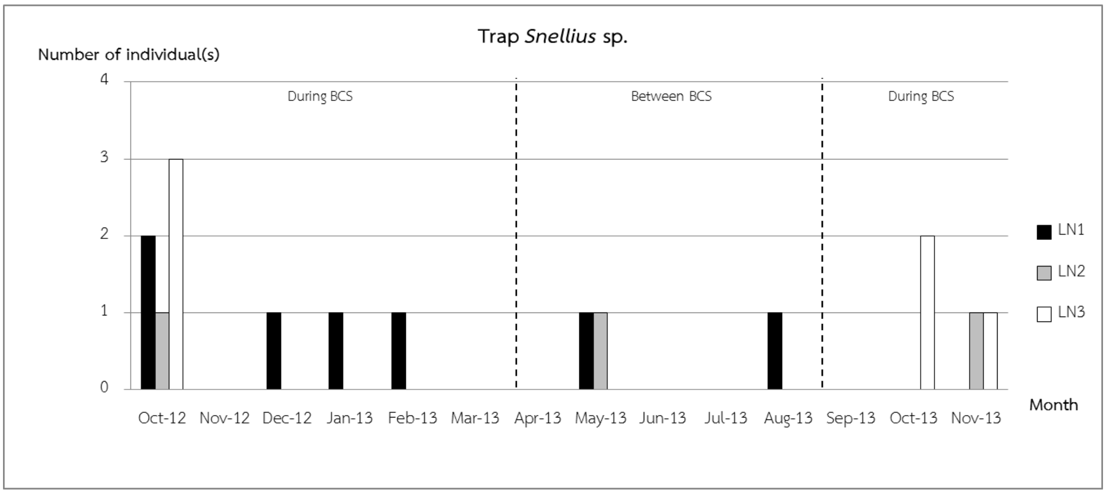

Figure 4-75 Abundance of *Snellius* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

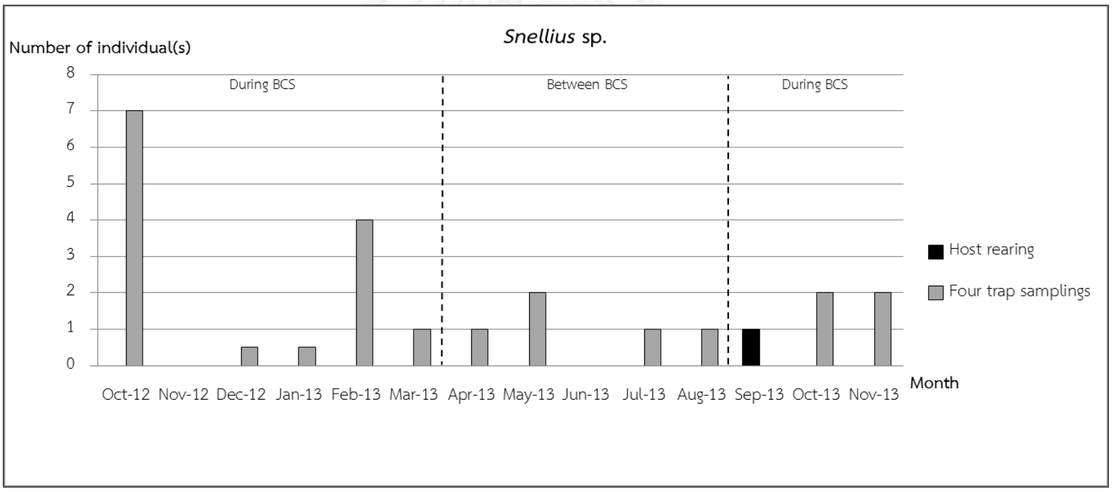

Figure 4-76 Number of *Snellius* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.11 Abundance of *Trathala* sp.

The highest abundance of *Trathala* sp. had been recorded from the trap samplings in November 2013 (29 individuals) at LN3 site, there was no significant difference of the abundance of *Trathala* sp. collected from the trap samplings among the three study sites (Kruskall-Wallis; *H=1.601, df=2, p=0.449*) (Figure 4-77). From the host rearing, numbers of *Trathala* sp. were recorded only in January - March 2013, but were recorded every month from the trap samplings (Figure 4-78). There was no significant difference of the *Trathala* sp. collected from the trap sampling during and between *Brassica* cultivated seasons (t-test; *t=1.474, df=12, p=0.166*), whereas, the abundance of *Trathala* sp. was positively correlated with the *Brassica* cultivated area and negatively correlated to the *Trathala* sp. from host rearing (Spearman correlation; r_S*=0.581, p=0.028* and r_S*=-0.683, p=0.036*, respectively) (Figure 4-79).

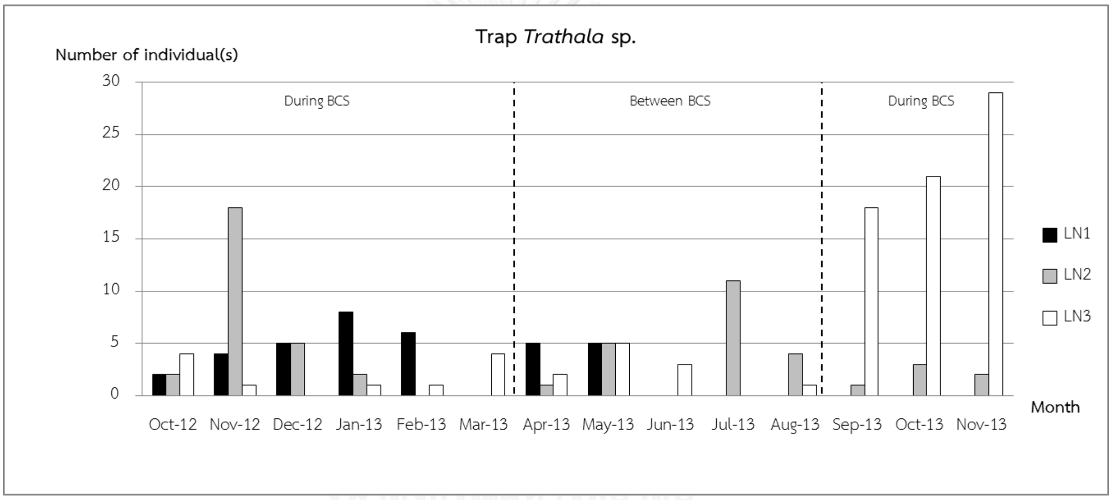

Figure 4-77 Abundance of *Trathala* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

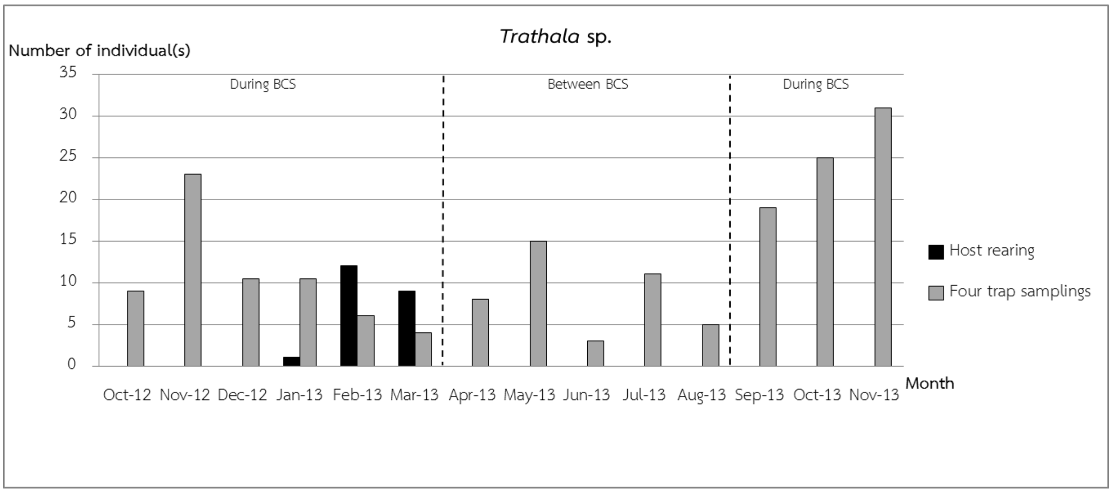

Figure 4-78 Number of *Trathala* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

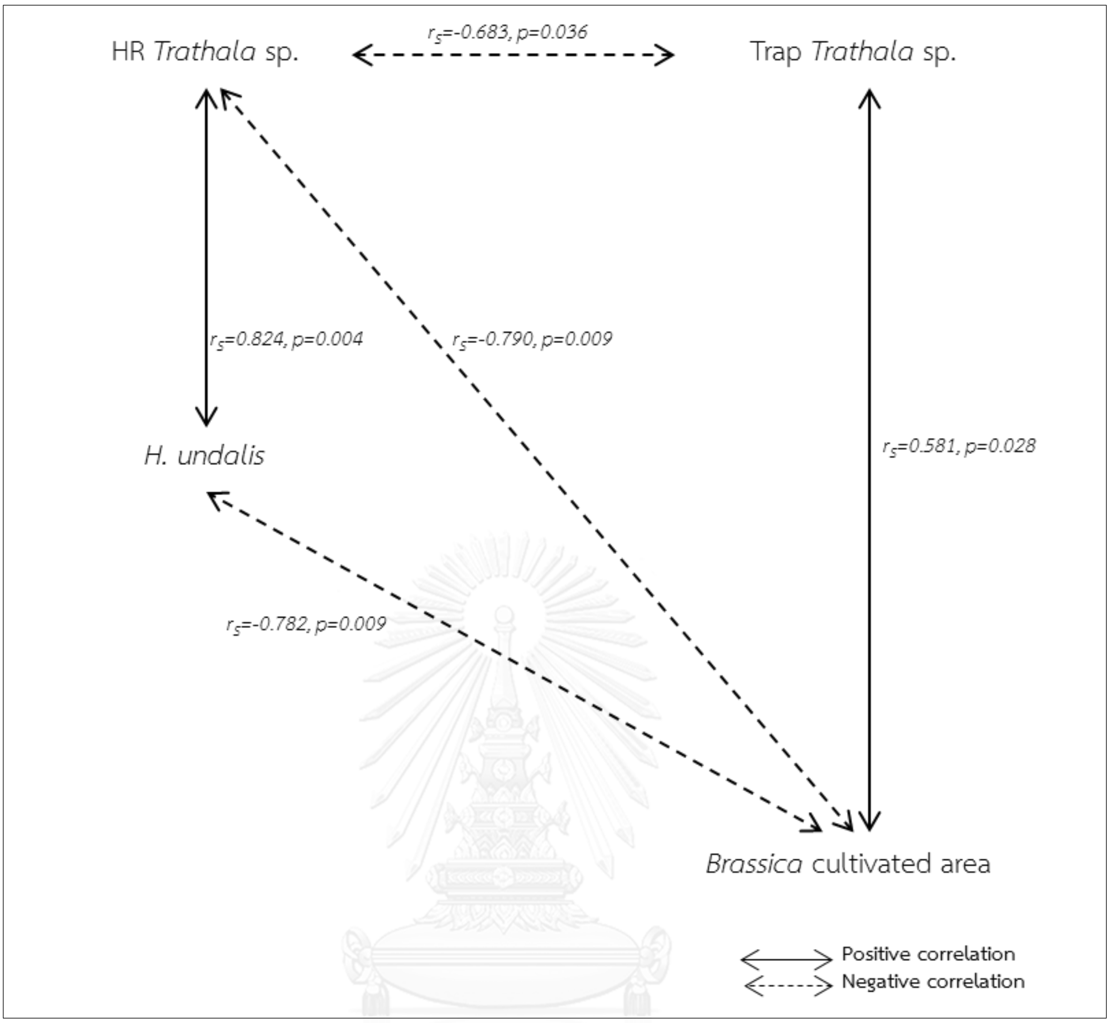

Figure 4-79 Spearman correlations between the *Brassica* cultivated area, lepidopteran host *H. undalis* and the number of *Trathala* sp. from host rearing and trap sampling during and between *Brassica* cultivated seasons (October 2012-November 2013)

4.5.12 Abundance of cryptinid wasp

A few specimens of cryptinid wasps had been collected from the trap samplings, and there was no significant difference of the specimens collected from the trap samplings among the three study sites (Kruskall-Wallis; *H=5.334, df=2, p=0.069*) (Figure 4-80). Although the numbers of cryptinid wasps collected from the trap samplings were very low, 10 individuals of the cryptinid wasps emerged from the host rearing (Figure 4-81). There was no significant difference of the cryptinid wasp abundance from the trap sampling during and between *Brassica* cultivated seasons (*Mann-Whitney U Statistic=21.500, T=36.500, p=0.926*).

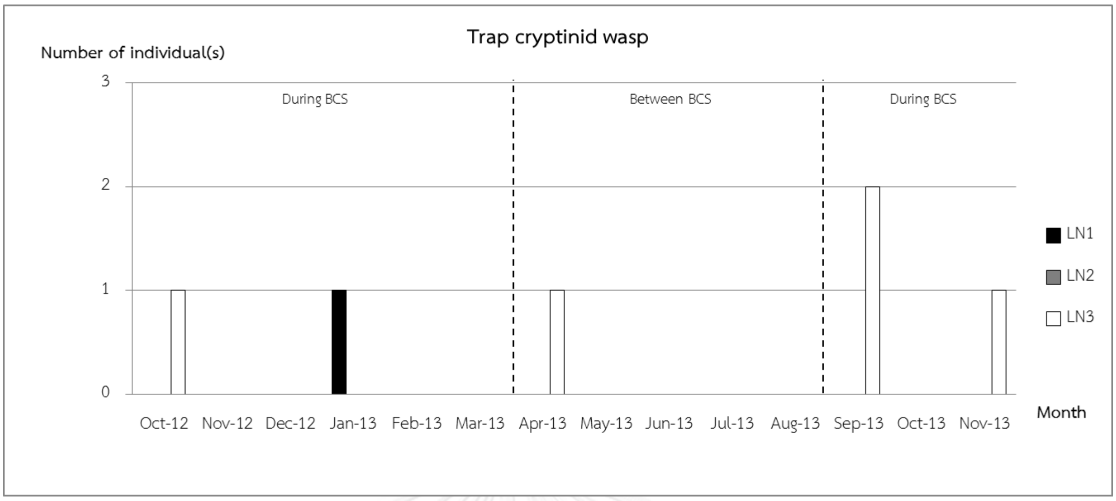

Figure 4-80 Abundance of cryptinid wasp recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

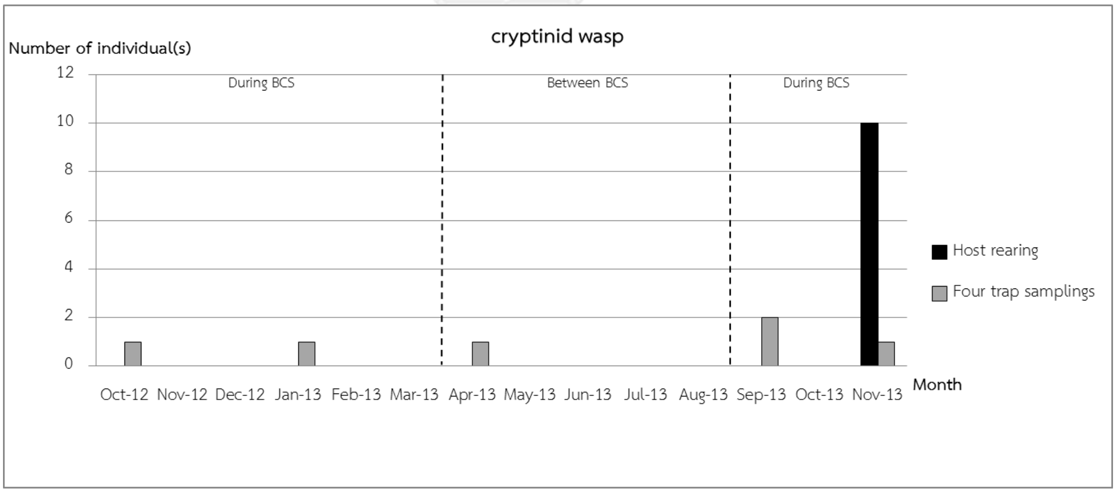

Figure 4-81 Number of cryptinid wasps collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.13 Abundance of *Brachymeria* sp.

There was no significant difference of *Brachymeria* sp. abundance collected from the trap samplings among the threes study sites (Kruskall-Wallis; *H=0.589, df=2, p=0.745)* (Figure 4-82). Only 7 individuals of *Brachymeria* sp. were recorded from the host rearing in March 2013 (Figure 4-83). There was no significant difference of the abundance of *Brachymeria* sp. collected from the trap samplings during and between *Brassica* cultivated seasons (*Mann-Whitney U Statistic=17.000, T=32.000, p=0.434*).

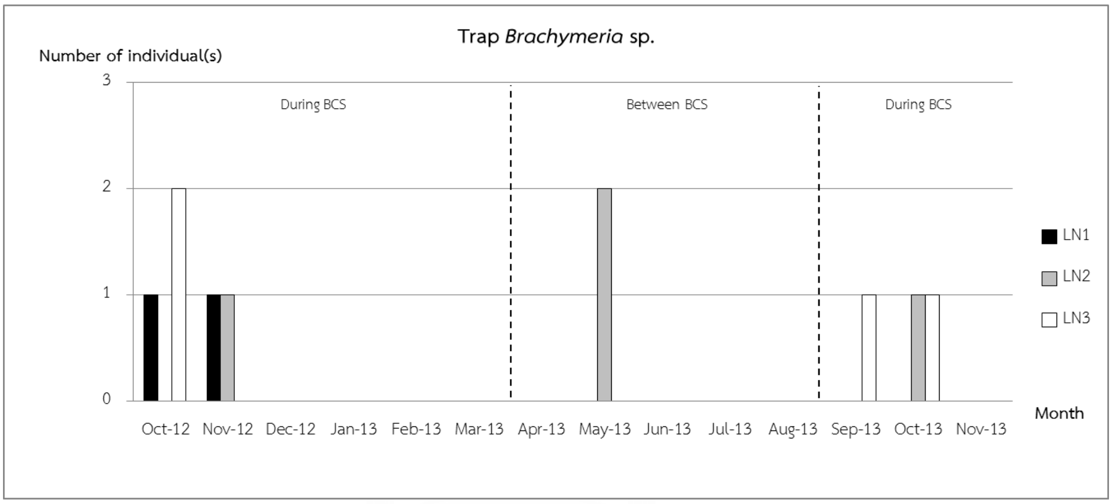

Figure 4-82 Abundance of *Brachymeria* sp. recorded from four trap sampling methods, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

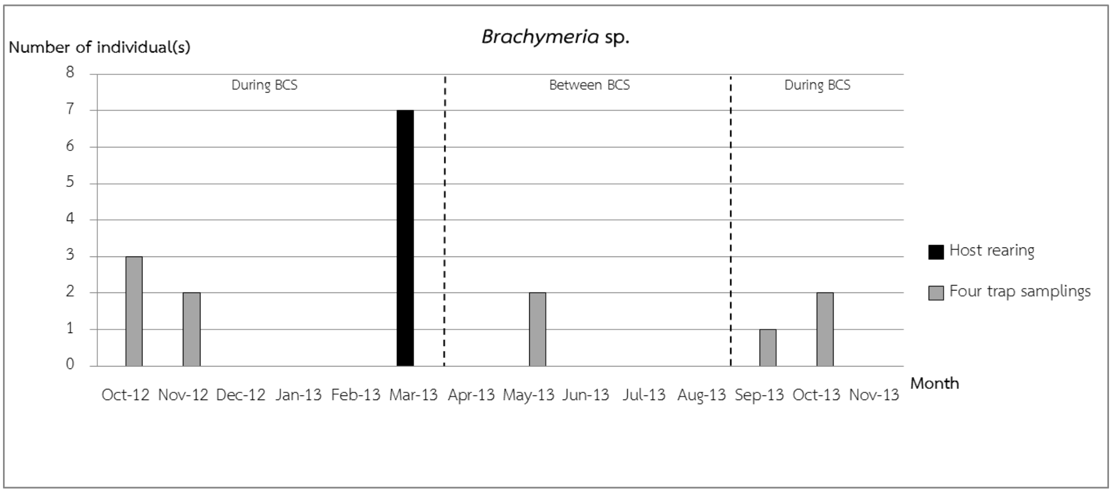

Figure 4-83 Number of *Brachymeria* sp. collected from the combination of four methods and host rearing during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) in the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

4.5.14 Diversity of beneficial parasitic wasps

The most diverse beneficial parasitic wasps were recorded in October 2013 with 1.96 and 0.15 of Shannon-Weiner and Simpson indices, respectively (Table 4-8). The species diversity (Figure 4-84) and total numbers (Figure 4-85) of thirteen beneficial parasitic wasps collected from the trap samplings each month were not significantly different among the three study sites, during and between *Brassica* cultivated seasons (Kruskall-Wallis; *H=3.591, df=2, p= 0.166* and *H=2.970, df=2, p= 0.226*, respectively). In addition, the total number of beneficial parasitic wasps collected from the trap samplings was no significant difference during and between *Brassica* cultivated seasons (t-test, *t=0.240, df=12, p=0.814*). Spearman correlation analysis showed the positive correlation among *Brassica* cultivated sites and variety of beneficial parasitic wasps collected from the trap samplings (r_S*=0.532, p=0.047*), while the total number of lepidopteran pests and total number of parasitoids from the host rearing were negatively correlated to the variety of the beneficial parasitic wasps from the trap sampling (r_S*=-0.755, p=0.016* and r_S*=-0.782, p=0.009*, respectively). Finally, the variety of beneficial parasitic wasps was positively correlated to the total number of beneficial parasitic wasps collected from the trap samplings (*r_S=0.610, p=0.020*) (Figure 4-86).

Table 4-8 Numbers of thirteen beneficial parasitic wasps recorded from trap samplings and the diversity indices; Shannon-Wiener and Simpson Indices during and between *Brassica* cultivated seasons (October 2012 - November 2013)

Beneficial parasitic wasps	2012			2013										
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Microplitis sp.	21	5	4	26	14	11	7	9	7	8	22	38	18	17
Mesochorus sp.	0	7	2	0	0	0	0	0	1	0	0	2	1	5
Diadegma sp.	16	7	2	11	2	3	8	3	6	5	2	17	33	21
Charops sp.	6	4	5	3	3	2	2	2	1	3	0	2	5	3
Metopius sp.	0	4	5	2	1	0	1	3	0	0	0	1	0	0
Dolichogenidae sp.	59	67	37	30	13	25	53	81	33	53	19	52	33	47
Therophilus sp.	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Chelonus sp.	15	29	16	20	14	8	48	60	30	28	11	15	27	11
Cotesia sp.	33	26	29	37	26	24	24	21	14	41	40	48	31	32
Snellius sp.	7	0	1	1	4	1	1	2	0	1	1	0	2	2
Trathala sp.	9	23	11	11	6	4	8	15	3	11	5	19	25	31
cryptinid wasp	1	0	0	1	0	0	1	0	0	0	0	2	0	1
Brachymeria sp.	3	2	0	0	0	0	0	2	0	0	0	1	2	0
Total no. of individuals	170	174	113	142	83	79	153	198	95	150	100	197	179	170
NO. of species	10	10	11	10	9	9	10	10	8	8	7	11	10	10
Shannon-Wiener Index	1.51	1.80	1.84	1.87	1.85	1.71	1.63	1.57	1.59	1.61	1.53	1.84	1.96	1.90
Simpson Index	0.18	0.22	0.21	0.18	0.19	0.23	0.25	0.28	0.25	0.24	0.26	0.19	0.15	0.18

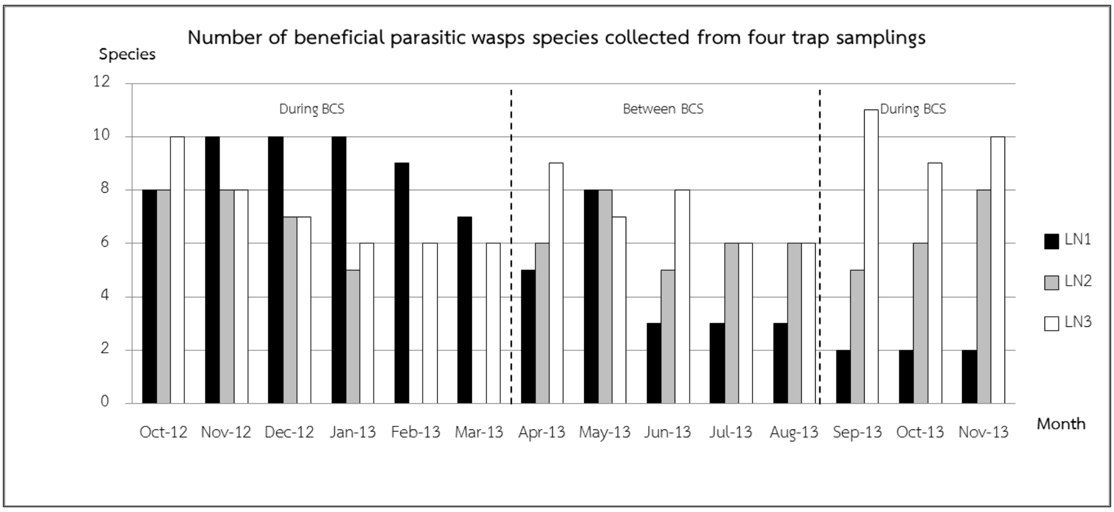

Figure 4-84 Number of beneficial parasitic wasps species recorded from four trap samplings, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) at Lainan Subdistrict, Wiang Sa District, Nan Province

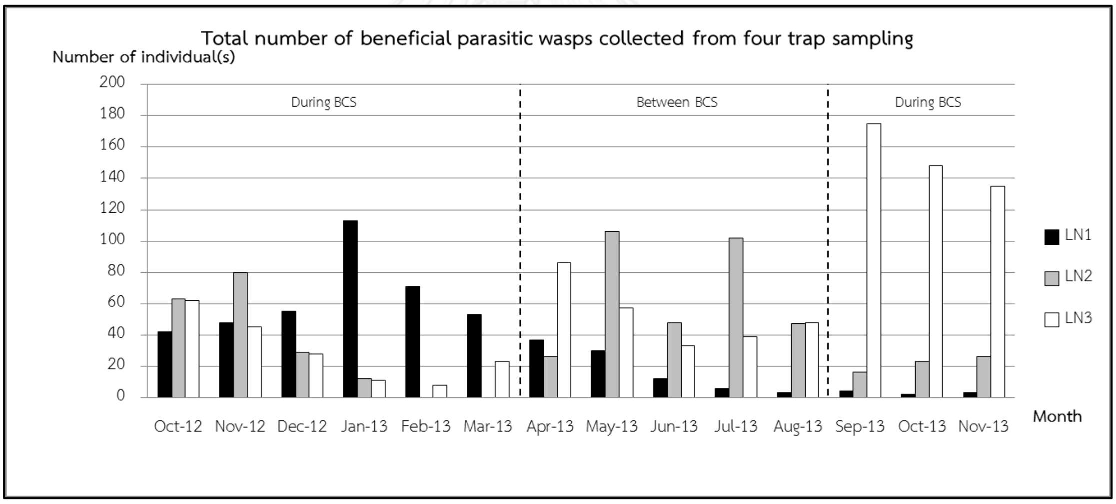

Figure 4-85 Total number of beneficial parasitic wasps collected from four trap samplings, during and between *Brassica* cultivated seasons (BCS) (October 2012 - November 2013) at Lainan Subdistrict, Wiang Sa District, Nan Province

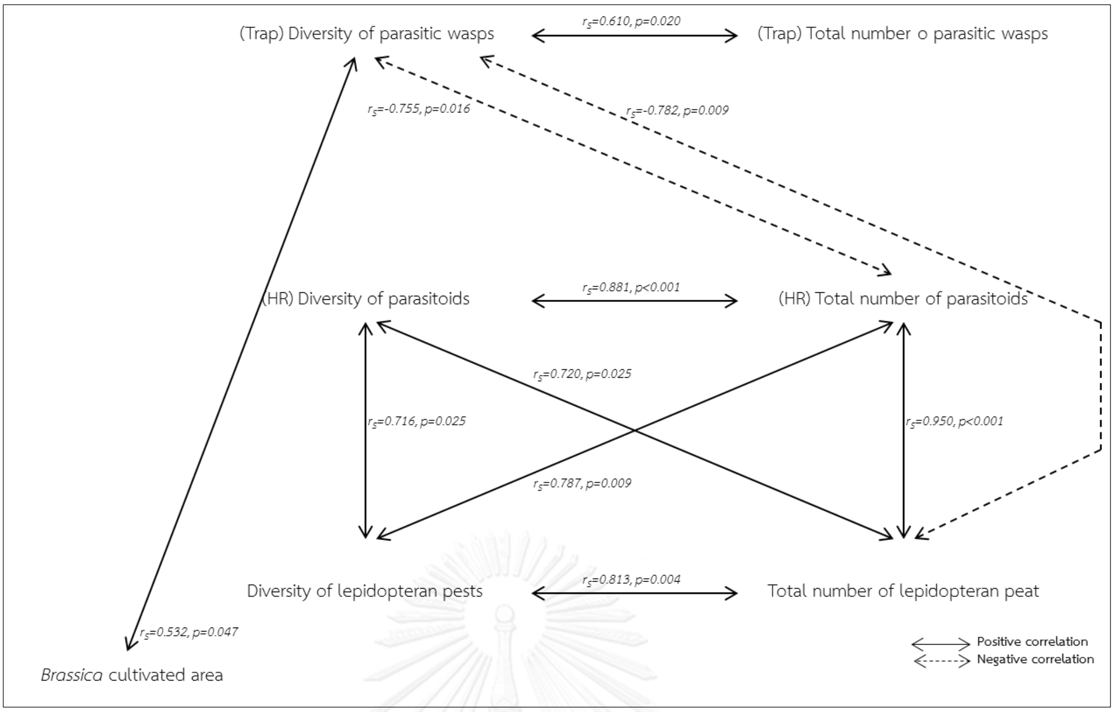

Figure 4-86 Spearman correlations between the size of *Brassica* cultivated areas; variety and total number of lepidopteran pests; variety and total number of parasitoids from host rearing; variety and total number of beneficial parasitic wasps collected from trap samplings during and between *Brassica* cultivated seasons (October 2012 - November 2013)

4.5 Other parasitic wasps

A total of forty parasitic wasp taxa were recorded from *Brassica* cultivation areas at Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 - November 2013); twelve subfamilies of parasitic wasps belong to the family Ichneumonidae, fifteen subfamilies of the family Braconidae and thirteen families of the superfamily Chalcidoidea. However, only twenty five taxa were reported to parasitize the lepidopteran hosts (Goulet and Huber 1993). Nine subfamilies of the family Ichneumonidae; Banchinae, Campopleginae, Cresmastinae, Cryptinae, Mesochorinae, Metopiinae, Nesomesochorinae, Ophioninae and Pimplinae (Table 4-9); ten subfamilies of the family Braconidae; Agathidinae, Braconinae, Cardiochilinae, Cheloninae, Macrocentrinae, Meteoridinae, Microgastrinae, Miracinae, Orgilinae and Rogadinae

(Table 4-10); and five families of the superfamily Chalcidoidea; Chalcididae, Encytidae, Eulophidae, Eupelmidae and Perilampidae were recorded in this study sites (Table 4-11).

Table 4-9 List of parasitic wasp subfamilies of the family Ichneumonidae collected from *Brassica* cultivation areas at Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 - November 2013)

Subfamilies	Hosts of parasitic wasps (Goulet and Huber, 1993)
Banchinae	Lepidoptera larvae
Campopleginae	Lepidoptera larvae, Coleoptera larvae and Raphidioptera
Cresmastinae	Lepidoptera larvae and Coleoptera larvae
Cryptinae	Holometobola pupae and prepupae
Diaplazantinae	Diptera eggs and larvae
Mesochorinae	Hyperparasitoids of primary parasitoids of Lepidoptera
Metopiinae	Lepidoptera larvae
Neorhaconinae	Pemphredonidae
Nesomesochorinae	Lepidoptera larvae
Ophioninae	Lepidoptera and Coleoptera
Orthocentrinae	Diptera
Pimplinae	Lepidoptera pupae and prepupae

Table 4-10 List of parasitic wasp subfamilies of the family Braconidae collected from *Brassica* cultivation areas at Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 - November 2013)

Subfamilies	Hosts of parasitic wasps (Goulet and Huber, 1993)
Agathidinae	Lepidoptera larvae
Alysiinae	Diptera larvae
Aphidiinae	Aphidae (Homoptera) nymphs and adults
Braconinae	Coleoptera, Lepidoptera, Diptera and Symphyta
Cardiochilinae	Lepidoptera larvae
Cheloninae	Lepidoptera eggs
Doryctinae	Coleoptera larvae and Embioptera
Euphorinae	Coleoptera, Hemiptera, Neuroptera, Psocoptera, Orthoptera and Hymenoptera
Macrocentrinae	Lepidoptera larvae
Meteoridinae	Lepidoptera larvae
Microgastrinae	Lepidoptera larvae
Miracinae	Lepidoptera larvae
Orgilinae	Lepidoptera larvae
Opiinae	Diptera larvae
Rogadinae	Lepidoptera larvae

Table 4-11 List of parasitic wasp families of the superfamily Chalcidoidea collected from *Brassica* cultivation areas at Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 - November 2013)

Families	Hosts of parasitic wasps (Goulet and Huber, 1993)
Agaonidae	Figs
Chalcididae	Lepidoptera, Diptera, Coleoptera and Hymenoptera
Encytidae	Coleoptera, Lepidoptera, Diptera and Symphyta
Eucharitidae	Hymenoptera, Thysanoptera and Phytophagous
Eulophidae	Lepidoptera, Diptera, Hymenoptera and Coleoptera
Eupelmidae	Lepidoptera and Diptera
Eurytomidae	Phytophagous and Entomophagous
Leucospidae	Hymenoptera
Mymaridae	Homoptera, Hemiptera, Psocoptera, Coleoptera, Orthoptera and Diptera
Perilampidae	Lepidoptera, Diptera, Coleoptera, Hymenoptera, Orthoptera, and Neuroptera
Pteromalidae	Homoptera, Diptera, Coleoptera and Phytophagous
Tetracampidae	Diptera and Coleoptera
Torymidae	Phytophagous

4.5.1 Abundance and diversity of other parasitic wasps

Abundance of each family and subfamily of the parasitic wasps collected from trap samplings in the three *Brassica* cultivation sites during and between *Brassica* cultivated seasons (October 2012 - November 2013), showed no significantly different of the parasitic wasps abundance in the three study sites in most taxa (Table 4-12).

However, the abundance of some taxa were significant among the study sites; subfamily Campopleginae, the abundance on the LN1 site is different from the LN3 site (*H=6.581, df=2, p= 0.037*, Figure 4-88); subfamily Ophioninae, the abundance on the LN2 site was different to the LN3 site (*H=9.959, df=2, p=0.007*, Figure 4-94); subfamily Orgilinae, the abundance on the LN3 site was different from the LN1 and the LN2 sites (*H=6.026, df=2, p=0.049*, Figure 4-104); subfamily Rogadinae, the abundance on the LN3 site was significantly different from the LN1 and the LN2 sites (*H=8.393, df=2, p=0.015*, Figure 4-105) family Eulophidae, the abundance on the LN3 site was different from the LN1 and the LN2 sites (*H=17.769, df=2, p<0.001*, Figure 4-108) and family Eupelmidae, the abundance on the LN2 site was different from the LN1 and the LN3 sites (*H=7.703, df=2, p=0.021*, Figure 4-109) (Table 4-12).

Additionally, the abundance of each family and subfamily of the parasitic wasps had been calculated on the large scale of their taxa. Abundance of the family Ichneumonidae was not significantly different among the three study sites (*H=2.047, df=2, p=0.359*, Figure 4-111), similar to those in the family Braconidae (*H=0.797, df=2, p=0.671*, Figure 4-112), while the abundance of the superfamily Chalcidoidea in the LN3 site was significantly different from the LN1 and the LN2 sites (*H=12.878, df=2, p=0.002*, Figure 4-113). However, there was no significantly different on total number of parasitic wasps taxa each month among the three study sites (*p=0.235*, Figure 4-114). During and between *Brassica* cultivated seasons, the abundance of each parasitic wasp taxa each month (LN1+LN2+LN3) were not significantly different among the cultivated seasons (Table 4-13).

Table 4-12 Parasitic wasps collected from *Brassica* crops in the three study sites (LN1, LN2 and LN3) at Lainan Subdistrict, Wiang Sa District, Nan Province (October 2012 - November 2013)

NO.	Taxa	Study sites			Kruskall-Wallis	Figure
		LN1	LN2	LN3		
Family Ichneumonidae		/	/	/	*H=2.047, df=2, p=0.359*	Figure 4-111
1	Banchinae	/	/		*H=2.103, df=2, p=0.349*	Figure 4-87
2	Campopleginae	/	/	/	*H=6.581, df=2, p=0.037*	Figure 4-88
3	Cresmastinae	/	/	/	*H=0.146, df=2, p=0.929*	Figure 4-89
4	Cryptinae	/	/	/	*H=0.058, df=2, p=0.971*	Figure 4-90
5	Mesochorinae	/	/	/	*H=1.440, df=2, p=0.487*	Figure 4-91
6	Metopiinae		/		*H=2.000, df=2, p=0.368*	Figure 4-92
7	Nesomesochorinae	/		/	*H=3.776, df=2, p=0.151*	Figure 4-93
8	Ophioninae	/	/	/	*H=9.959, df=2, p=0.007*	Figure 4-94
9	Pimplinae	/	/	/	*H=1.454, df=2, p=0.483*	Figure 4-95
Family Braconidae		/	/	/	*H=0.797, df=2, p=0.671*	Figure 4-112
1	Agathidinae			/	*H=2.000, df=2, p=0.368*	Figure 4-96
2	Braconinae	/	/	/	*H=1.804, df=2, p=0.406*	Figure 4-97
3	Cardiochilinae	/	/	/	*H=2.627, df=2, p=0.269*	Figure 4-98
4	Cheloninae	/	/	/	*H=2.689, df=2, p=0.261*	Figure 4-99
5	Macrocentrinae	/		/	*H=3.058, df=2, p=0.217*	Figure 4-100
6	Meteoridinae	/		/	*H=1.025, df=2, p=0.599*	Figure 4-101
7	Microgastrinae	/	/	/	*H=1.017, df=2, p=0.601*	Figure 4-102
8	Miracinae		/		*H=2.000, df=2, p=0.368*	Figure 4-103
9	Orgilinae	/		/	*H=0.626, df=2, p=0.049*	Figure 4-104
10	Rogadinae	/	/	/	*H=8.393, df=2, p=0.015*	Figure 4-105
Superfamily Chalcidoidea		/	/	/	*H=12.878, df=2, p=0.359*	Figure 4-113
1	Chalcididae	/	/	/	*H=4.802, df=2, p=0.091*	Figure 4-106
2	Encytidae	/	/	/	*H=1.815, df=2, p=0.404*	Figure 4-107
3	Eulophidae	/	/	/	*H=17.769, df=2, p<0.001*	Figure 4-108
4	Eupelmidae	/	/	/	*H=7.703, df=2, p=0.021*	Figure 4-109
5	Perilampidae	/		/	*H=1.025, df=2, p=0.599*	Figure 4-110
Total taxa					*p=0.235*	Figure 4-114

Table 4-13 Abundance of parasitic wasps collected from *Brassica* crops in the three study sites (LN1, LN2 and LN3) at Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 - November 2013)

NO.	Taxa	During and between Brassica cultivated seasons
Family Ichneumonidae		*t-test, t=1.544, df=12, p=0.149*
1	Banchinae	*Mann-Whitney U Statistic=15.000, T=30.000, p=0.190*
2	Campopleginae	*Mann-Whitney U Statistic=13.500, T=34.500, p=0.121*
3	Cresmastinae	*Mann-Whitney U Statistic=21.500, T=38.500, p=0.946*
4	Cryptinae	*t-test, t=1.474, df=12, p=0.166*
5	Mesochorinae	*Mann-Whitney U Statistic=10.000, T=25.000, p=0.062*
6	Metopiinae	*Mann-Whitney U Statistic=18.000, T=42.000, p=0.233*
7	Nesomesochorinae	*Mann-Whitney U Statistic=12.500, T=27.500, p=0.106*
8	Ophioninae	*Mann-Whitney U Statistic=14.500, T=29.500, p=0.307*
9	Pimplinae	*Mann-Whitney U Statistic=18.500, T=41.500, p=0.557*
Family Braconidae		*t-test, t=0.512, df=12, p=0.618*
1	Agathidinae	*Mann-Whitney U Statistic=18.000, T=42.000, p=0.233*
2	Braconinae	*t-test, t=1.971, df=12, p=0.072*
3	Cardiochilinae	*Mann-Whitney U Statistic=20.000, T=35.000, p=0.779*
4	Cheloninae	*Mann-Whitney U Statistic=10.000, T=50.000, p=0.109*
5	Macrocentrinae	*Mann-Whitney U Statistic=15.000, T=30.000, p=0.194*
6	Meteoridinae	*Mann-Whitney U Statistic=17.500, T=32.500, p=0.323*
7	Microgastrinae	*t-test, t=0.621, df=12, p=0.546*
8	Miracinae	*Mann-Whitney U Statistic=18.000, T=42.000, p=0.233*
9	Orgilinae	*Mann-Whitney U Statistic=10.000, T=25.000, p=0.061*
10	Rogadinae	*t-test, t=0.470, df=12, p=0.646*
Superfamily Chalcidoidea		*Mann-Whitney U Statistic=18.000, T=33.000, p=0.592*
1	Chalcididae	*t-test, t=-1.826, df=12, p=0.093*
2	Encytidae	*Mann-Whitney U Statistic=21.000, T=36.000, p=0.886*
3	Eulophidae	*Mann-Whitney U Statistic=17.500, T=32.500, p=0.548*
4	Eupelmidae	*t-test, t=0.938, df=12, p=0.367*
5	Perilampidae	*Mann-Whitney U Statistic=17.500, T=32.500, p=0.323*
Total taxa		*t-test, t=1.094, df=12, p=0.295*

Abundance of subfamily Campopleginae was positively correlated to the *Brassica* cultivation area and the variety of *Brassica* cultivars (Spearman correlation; r_S*=0.646, p=0.012* and r_S*=0.546, p=0.034*, respectively). Similarly to the subfamily Mesochorinae, the abundance was positively correlated to the size of *Brassica* cultivation area and variety of *Brassica* cultivars (r_S*=0.685, p=0.006* and r_S*=0.750, p=0.001*, respectively), while the subfamilies Cryptinae, Nesomesochorinae, Braconinae, Macrocentrinae, Meteoridinae, Orgilinae and family Ichneumonidae (r_S*=0.559, p=0.022;* r_S*=0.610, p=0.209;* r_S*=0.585, p=0.026;* r_S*=0.672, p=0.008*; r_S*=0.559, p=0.036;* r_S*=0.589, p=0.026* and r_S*=0.641, p=0.013*, respectively) (Figure 4-115).

Abundance of the family Ichneumonidae was positively correlated to the abundance of the subfamilies Campopleginae, Cryptinae and Nesomesochorinae (r_S*=0.882, p<0.001*, r_S*=0.984, p<0.001* and r_S*=0.589, p=0.026*, respectively). The number of parasitic wasps family in Braconidae was positively correlated to the subfamilies Cardiochilinae, Meteoridinae, Microgastrinae, Cheloninae and Family Ichneumonidae (r_S*=0.829, p<0.001,* r_S*=0.608, p=0.020,* r_S*=0.748, p=0.001,* r_S*=0.590, p=0.025* and r_S*=0.761, p=0.001*, respectively). Moreover, families Eulophidae and Eupelmidae were positively correlated to the superfamily Chalcidoidea (r_S*=0.975, p<0.001* and r_S*=0.732, p=0.002*, respectively). Finally, number of total taxa or the diversity of parasitic wasps were positively correlated to the subfamily Campoplegibae (r_S*=0.698, p=0.005*); subfamily Cryptinae (r_S*=0.872, p<0.001*); subfamily Nesomesochorinae (r_S*=0.558, p=0.0255*); subfamily Cardiochilinae (r_S*=0.643, p=0.017*); subfamily Meteoridinae (r_S*=0.566, p=0.034*); subfamily Microgastrinae (r_S*=0.706, p=0.004*); family Ichneumonidae (r_S*=0.871, p<0.001*) and family Braconidae (r_S*=0.778, p<0.001*) (Figure 4-116)

Diversity of parasitic wasps on *Brassica* cultivation areas was measured in taxa level. The diversity was diverse at the beginning of the cultivated season, and the most diverse parasitoid was recorded in November 2012 with 2.30 and 0.14 of Shannon-Weiner and Simpson indices, respectively (Table 4-14). The prevalence index identifies the dominant taxa with the highly abundant and density from the trap samplings, subfamily Microgastrinae (*Microplitis* sp., *Cotesia* sp., *Dolichogenidae* sp. and *Snellius* sp.) was one of the high prevalence index (Figure 4-117).

Table 4-14 Abundance of parasitic wasp taxa collected at Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 - November 2013)

Taxa	2012			2013										
	October	November	December	January	February	March	April	May	June	July	August	September	October	November
Banchinae	1	0	0	1	0	1	0	0	0	0	0	0	0	0
Campopleginae	9	7	1	7	0	2	0	2	1	7	0	4	20	4
Cresmastinae	2	2	1	6	2	0	3	5	4	2	1	6	11	2
Cryptinae	17	33	2	5	2	4	3	9	4	3	2	12	19	16
Mesochorinae	0	5	1	1	0	0	0	0	0	0	0	0	2	6
Metopiinae	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Nesomesochorinae	0	1	0	1	0	0	0	0	0	0	0	1	1	0
Ophioninae	9	28	5	1	3	5	1	5	3	1	2	3	1	2
Pimpilinae	0	4	0	0	0	0	0	4	0	0	1	1	0	0
Agathidinae	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Braconinae	40	40	6	13	25	24	18	6	6	5	8	11	12	13
Cardiochilinae	6	33	0	0	1	0	0	1	0	2	1	1	3	0
Cheloninae	8	11	0	8	14	0	5	46	31	22	6	3	17	2
Macrocentrinae	0	8	0	0	0	0	0	0	0	0	0	0	1	4
Meteoridinae	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Microgastrinae	40	43	8	28	12	24	7	30	18	41	30	42	33	37
Miracinae	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Orgilinae	0	3	0	2	0	1	0	0	0	0	0	0	1	2
Rogadinae	16	7	2	3	15	4	11	4	3	8	11	4	14	14
Chalcididae	3	6	0	4	0	2	6	6	6	12	2	2	9	3
Encytidae	2	13	1	0	1	2	3	2	0	0	0	0	0	0
Eulophidae	46	102	37	127	60	30	27	120	54	17	23	44	23	21
Eupelmidae	10	12	2	6	3	6	4	5	2	1	2	3	0	0
Perilamidae	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Total no. of individuals	210	360	66	213	139	105	88	249	132	121	89	137	167	127
No. of taxa	15	20	11	15	12	12	11	17	11	12	12	14	15	14
Shannon -Weiner Index	2.20	2.36	1.59	1.60	1.75	1.91	2.01	1.78	1.74	1.98	1.84	1.88	2.30	2.11
Simpson Index	0.14	0.14	0.34	0.36	0.25	0.20	0.17	0.28	0.25	0.19	0.22	0.23	0.12	0.16

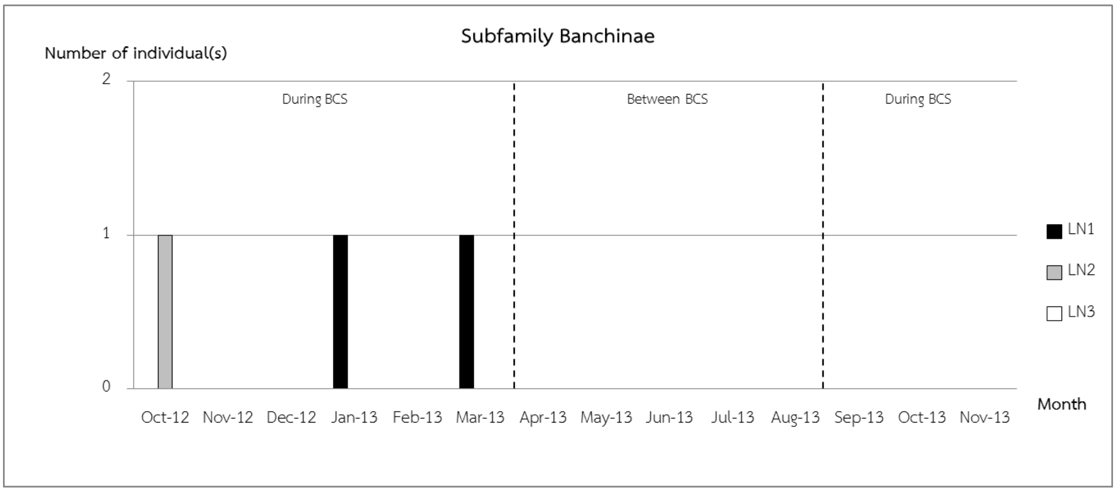

Figure 4-87 Abundance of subfamily Banchinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

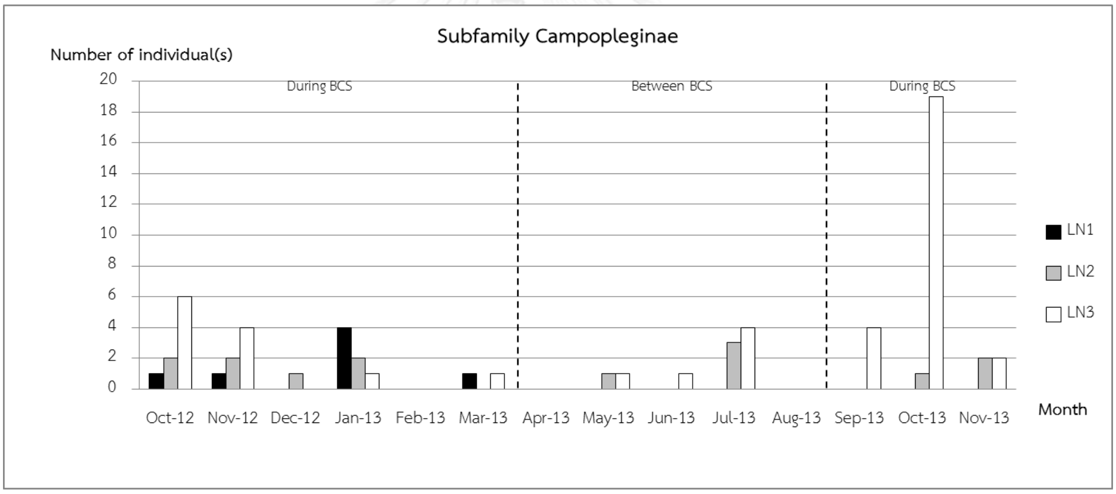

Figure 4-88 Abundance of subfamily Campopleginae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

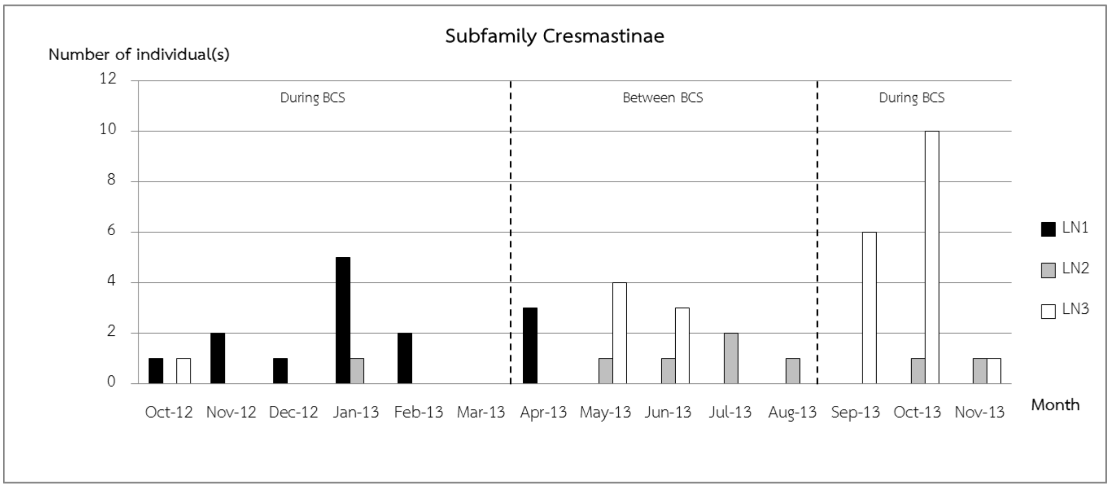

Figure 4-89 Abundance of subfamily Cresmastinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

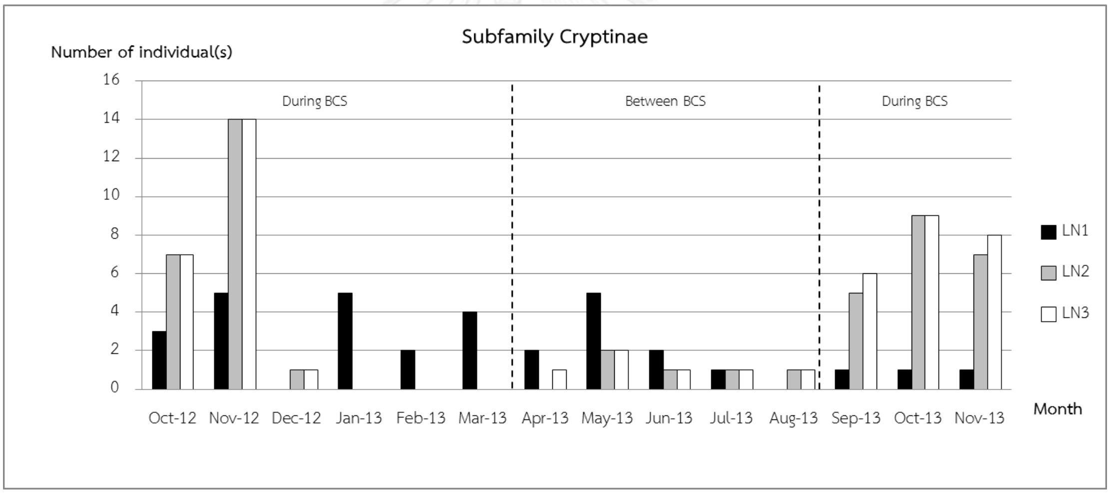

Figure 4-90 Abundance of subfamily Cryptinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

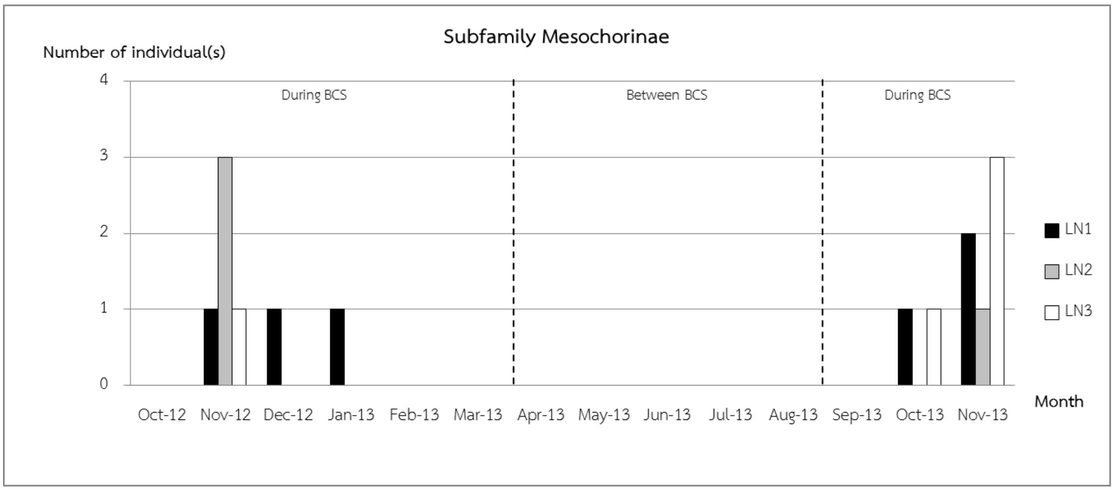

Figure 4-91 Abundance of subfamily Mesochorinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

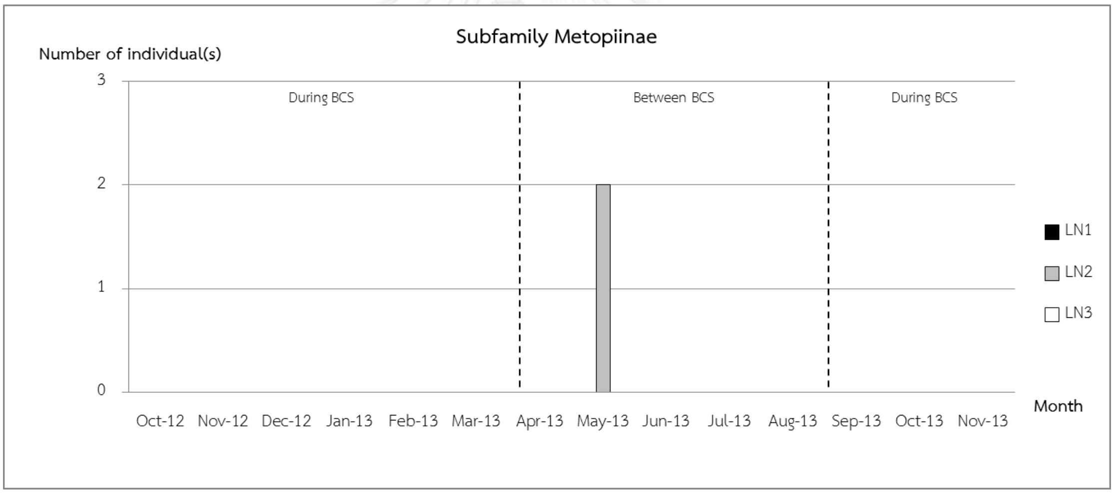

Figure 4-92 Abundance of subfamily Metopiinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

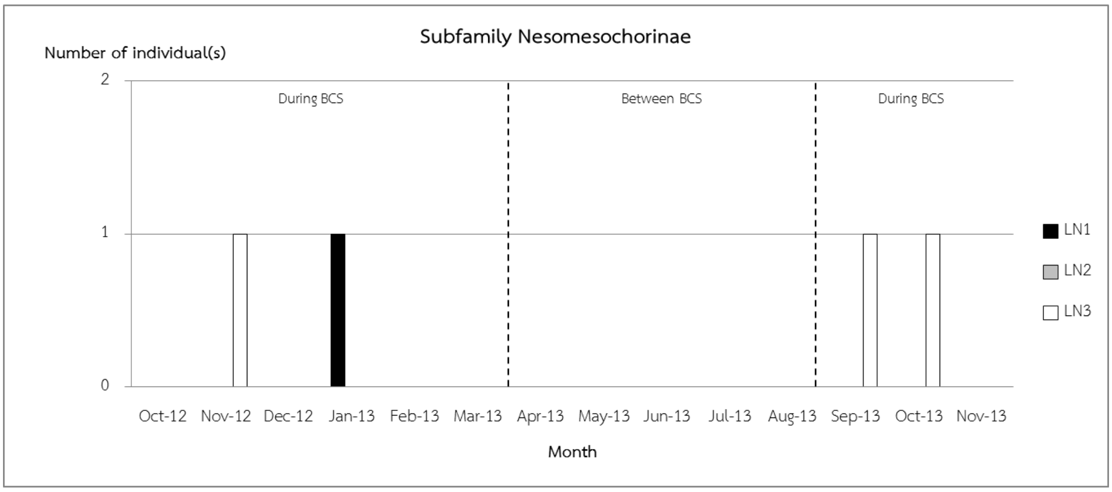

Figure 4-93 Abundance of subfamily Nesomesochorinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

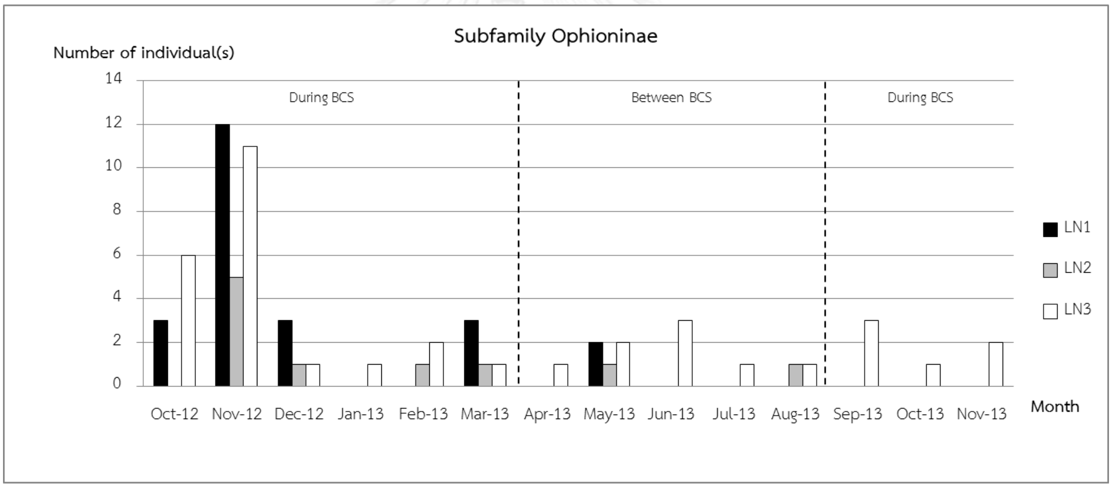

Figure 4-94 Abundance of subfamily Ophioninae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

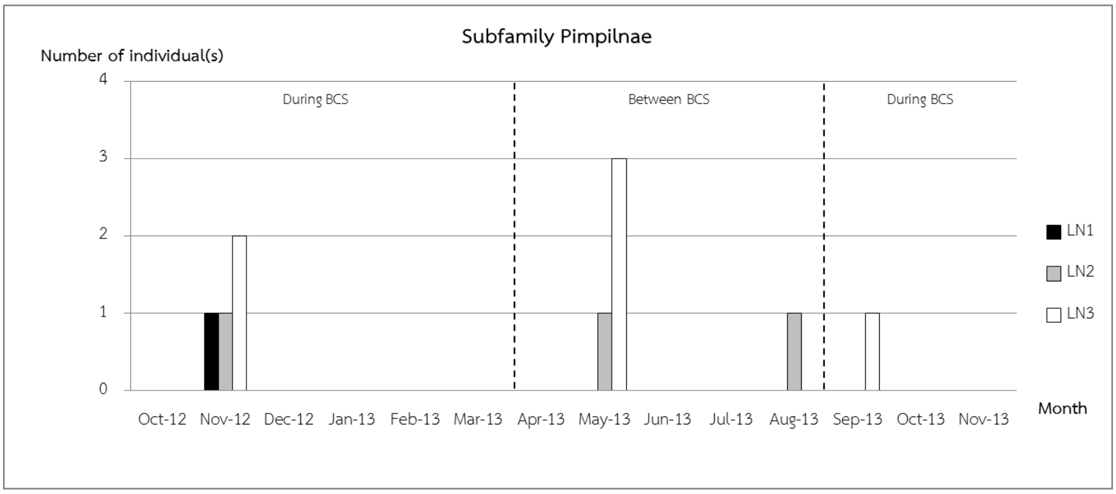

Figure 4-95 Abundance of subfamily Pimplinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

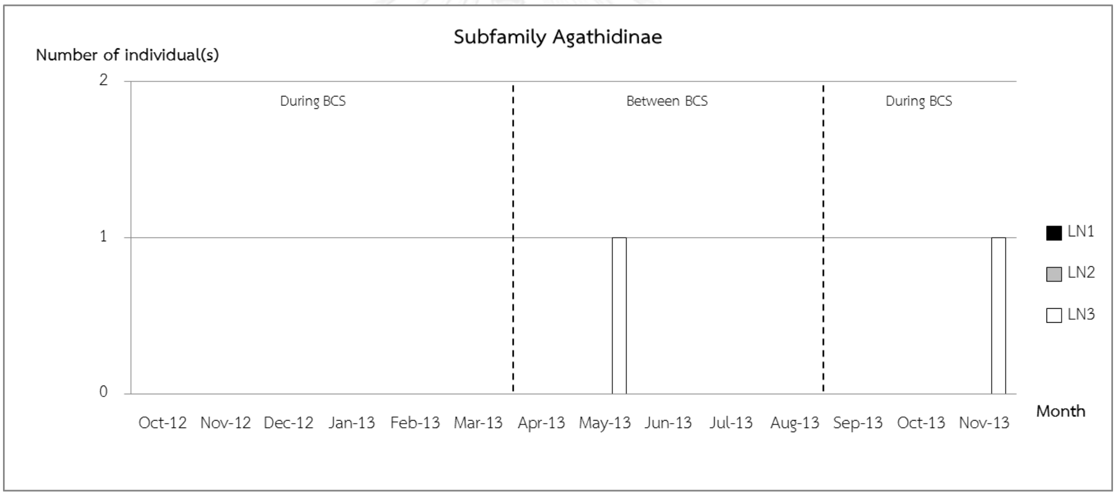

Figure 4-96 Abundance of subfamily Agathidinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

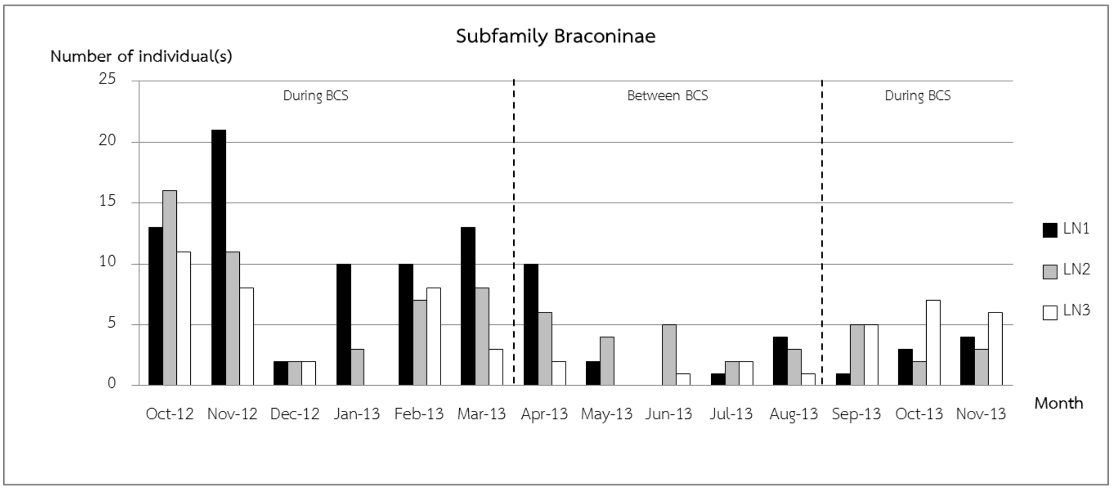

Figure 4-97 Abundance of subfamily Braconinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

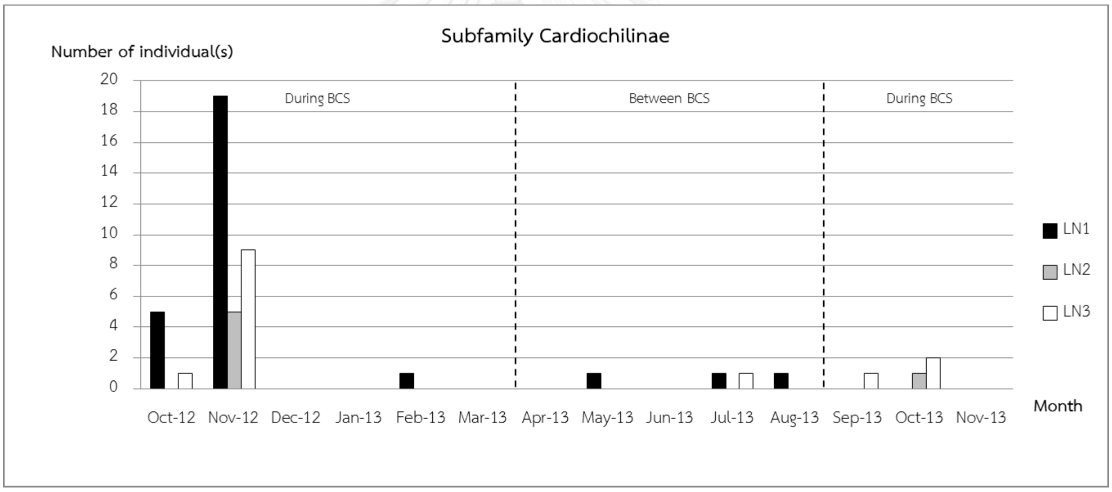

Figure 4-98 Abundance of subfamily Cardiochilinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

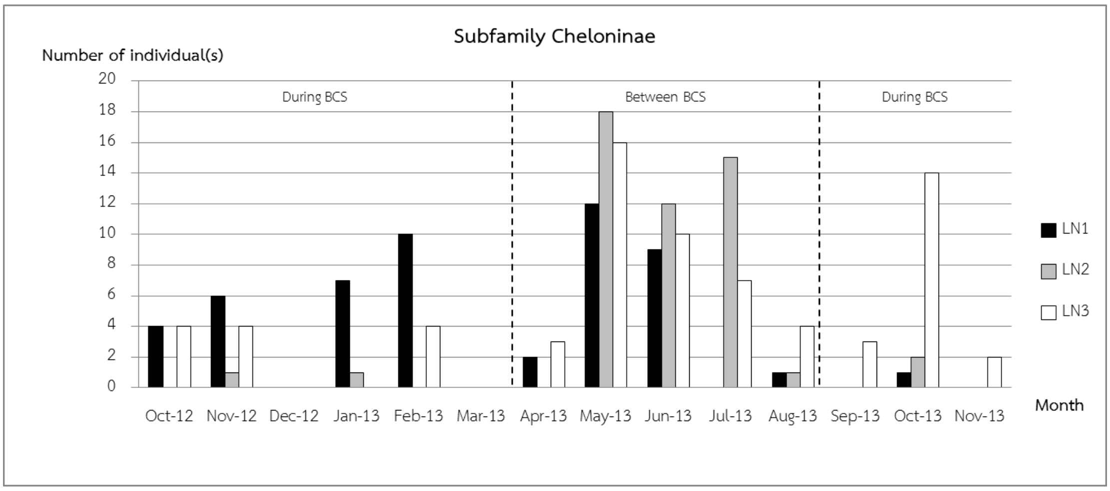

Figure 4-99 Abundance of subfamily Cheloninae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

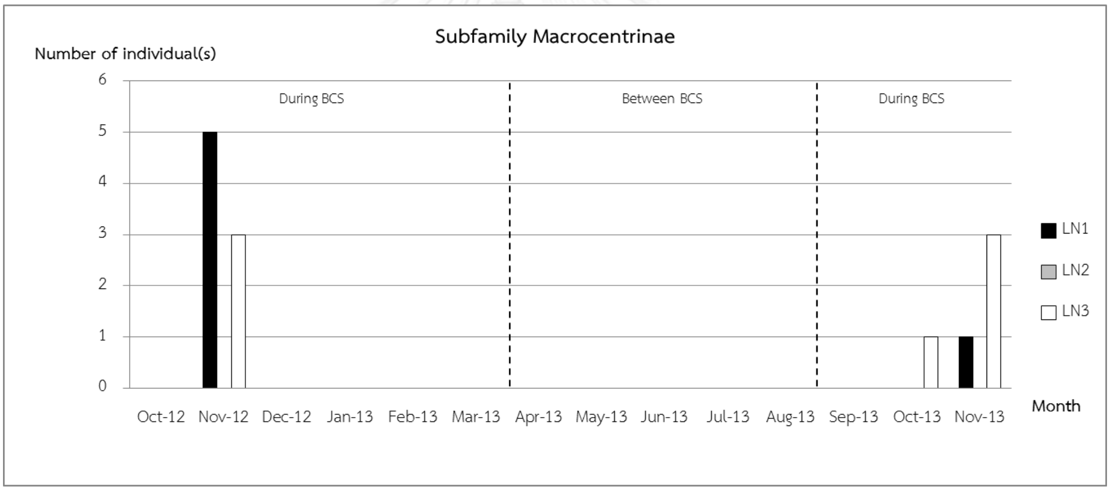

Figure 4-100 Abundance of subfamily Macrocentrinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

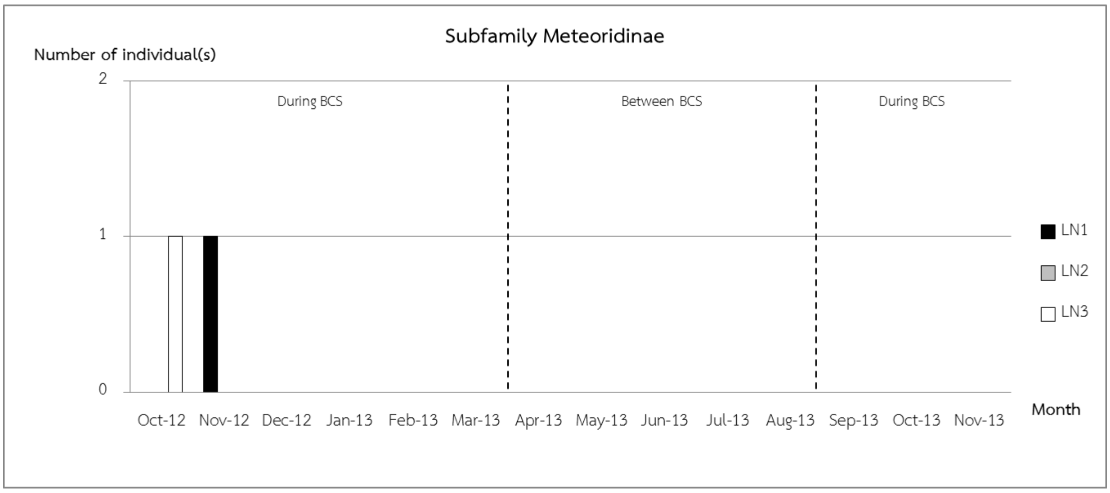

Figure 4-101 Abundance of subfamily Meteoridinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

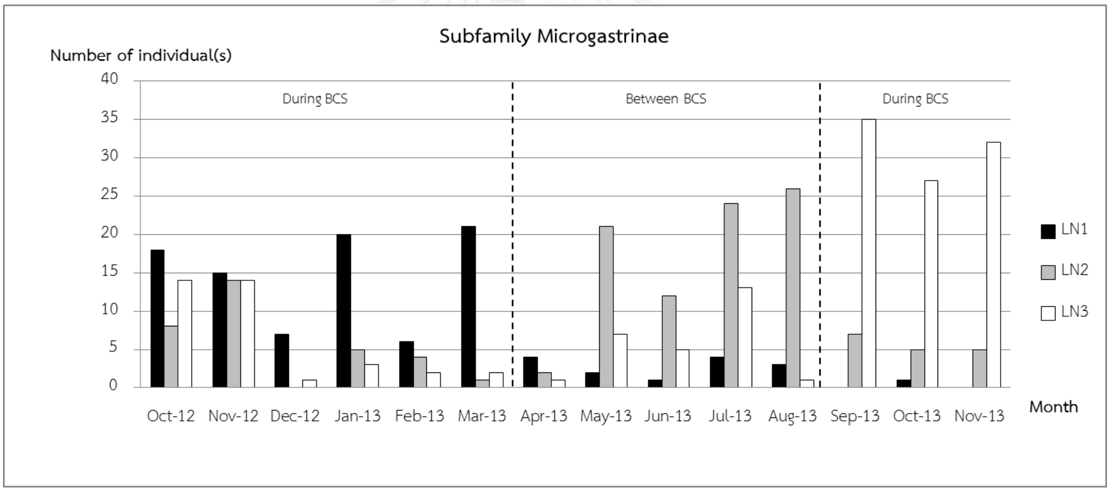

Figure 4-102 Abundance of subfamily Microgastrinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

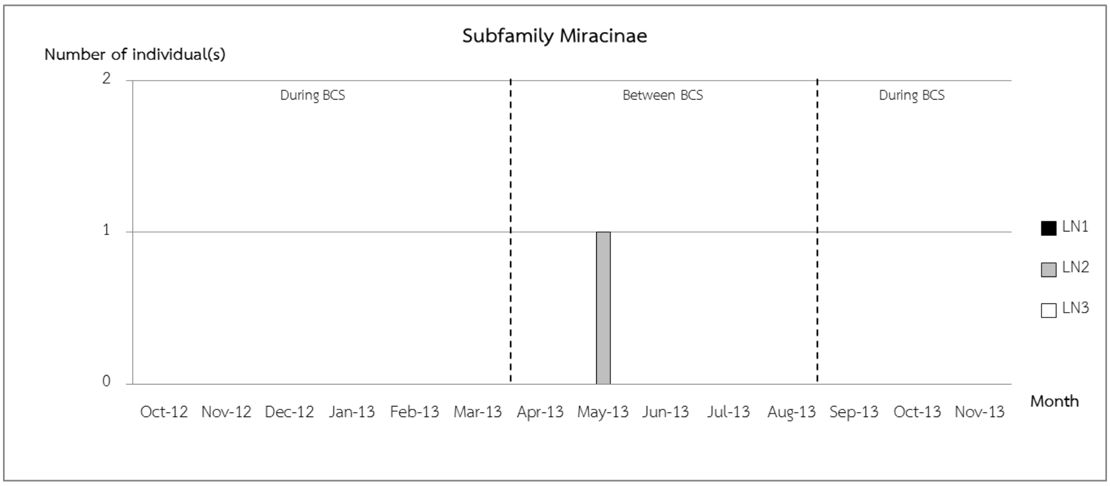

Figure 4-103 Abundance of subfamily Miracinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

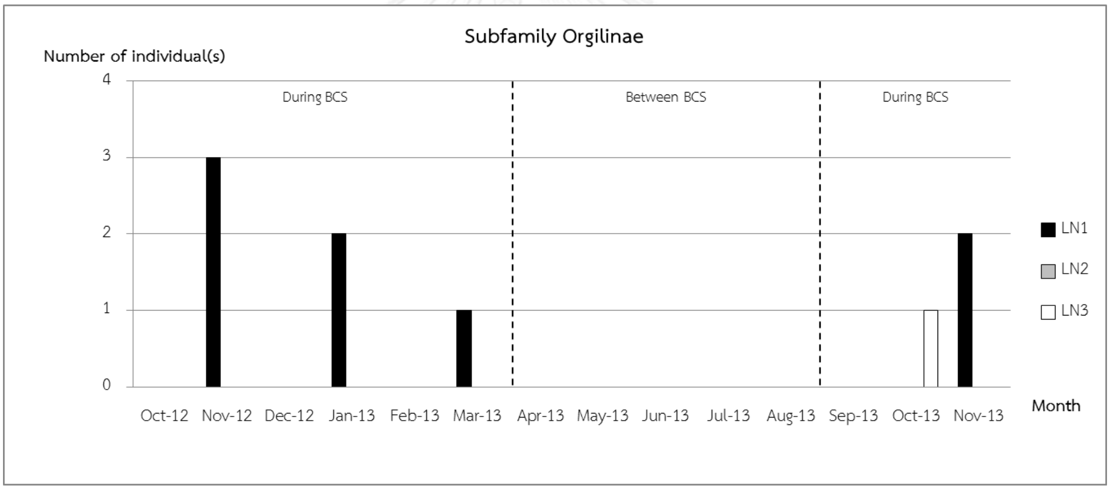

Figure 4-104 Abundance of subfamily Orgilinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

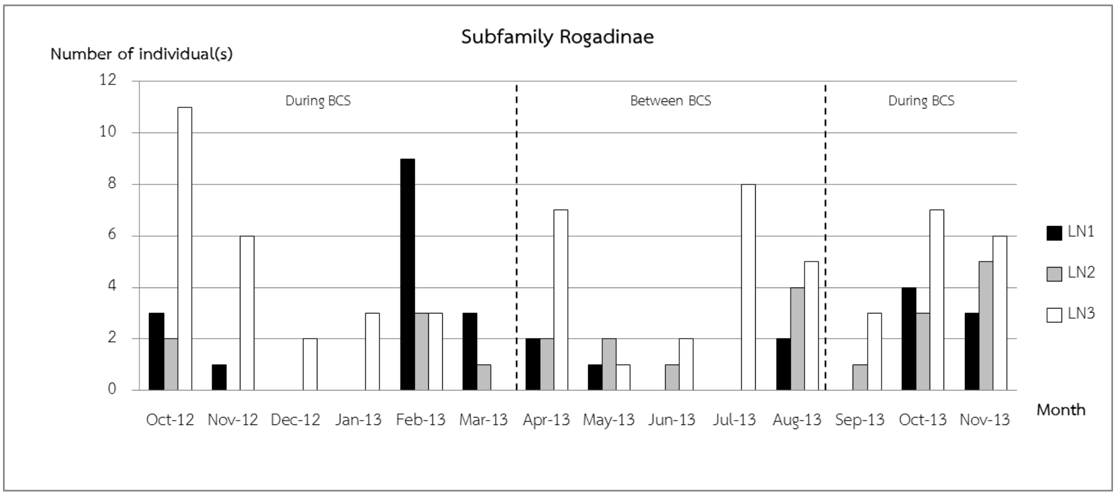

Figure 4-105 Abundance of subfamily Rogadinae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

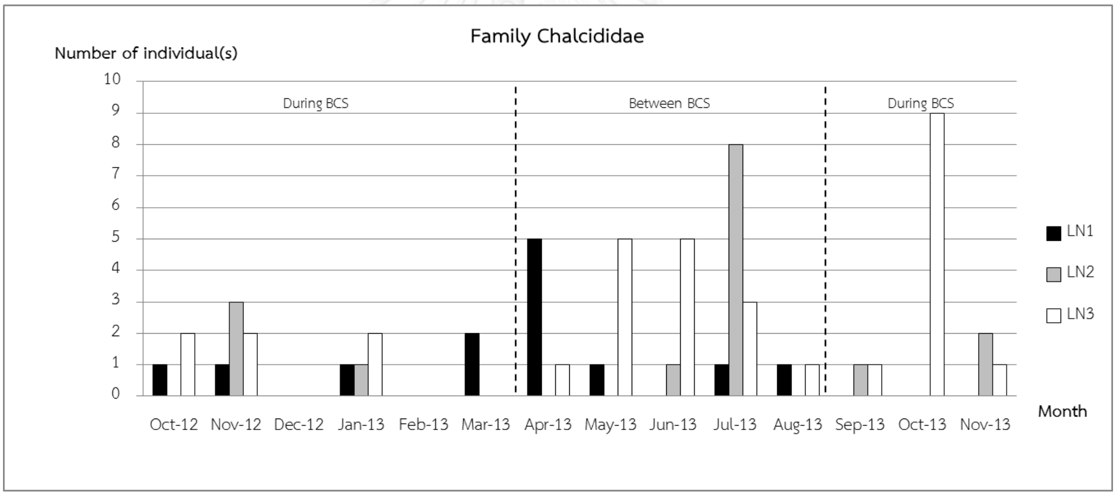

Figure 4-106 Abundance of family Chalcididae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

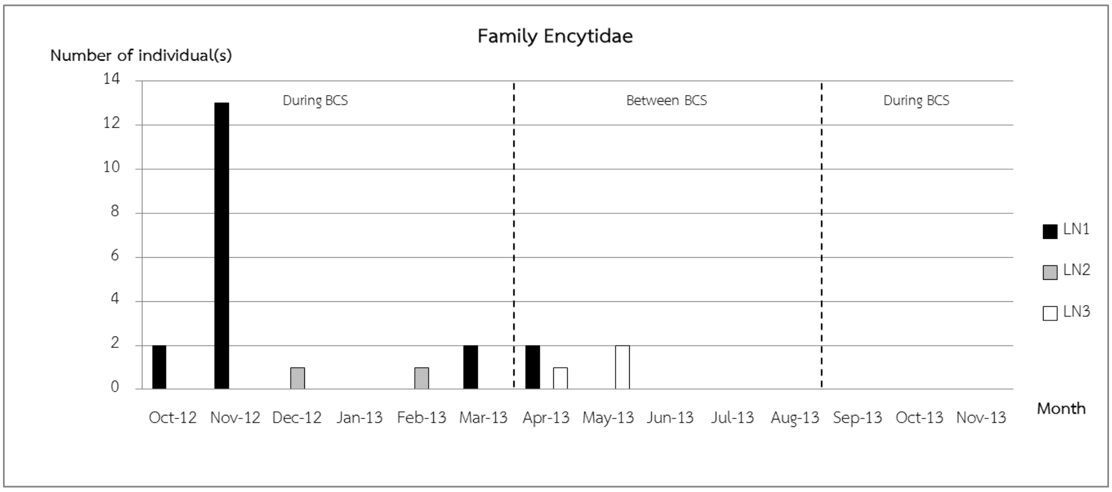

Figure 4-107 Abundance of family Encytidae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

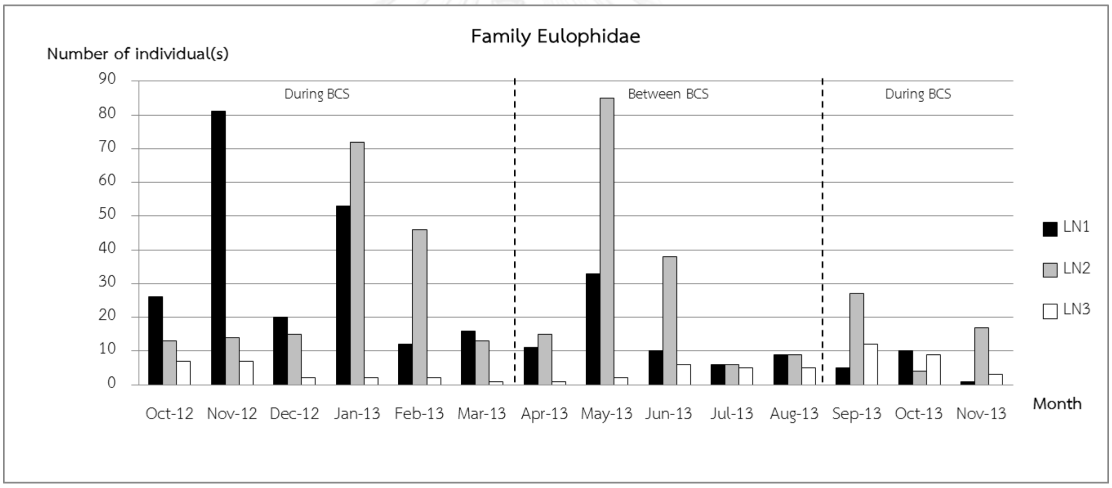

Figure 4-108 Abundance of family Eulophidae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

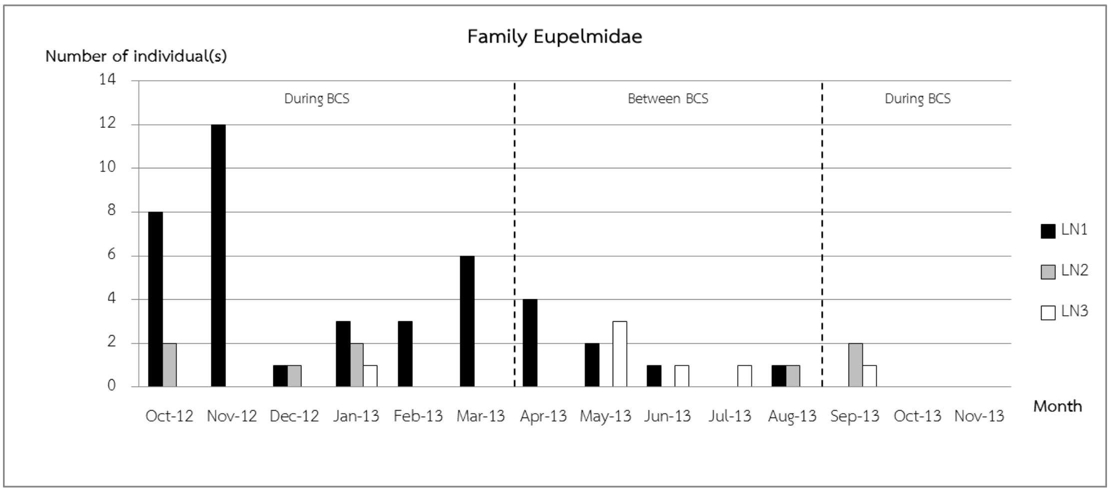

Figure 4-109 Abundance of family Eupelmidae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

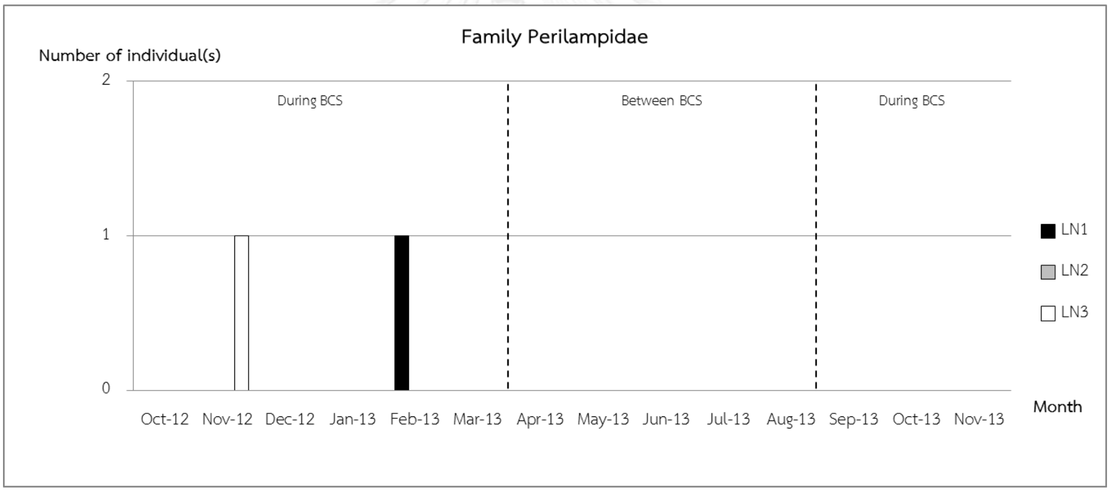

Figure 4-110 Abundance of family Perilampidae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

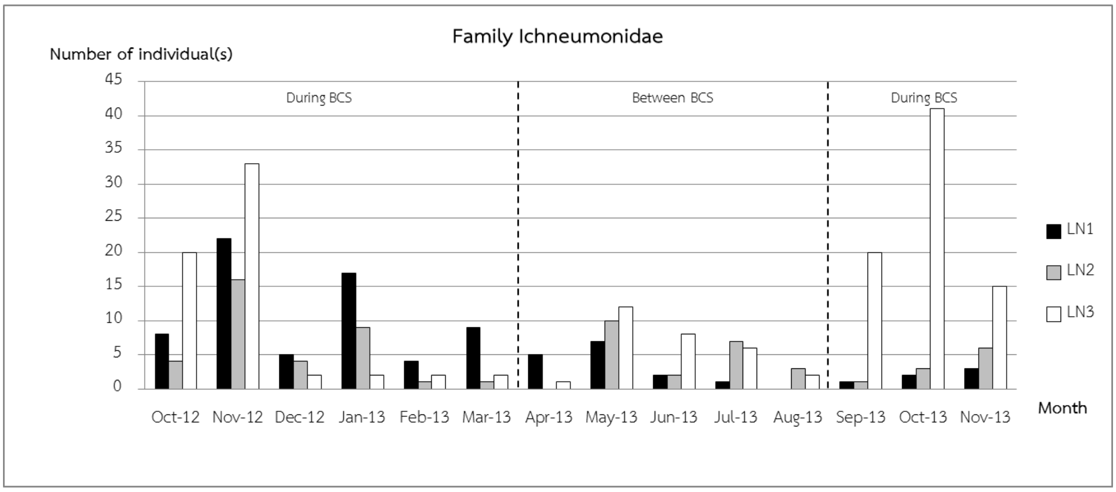

Figure 4-111 Abundance of family Ichneumonidae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

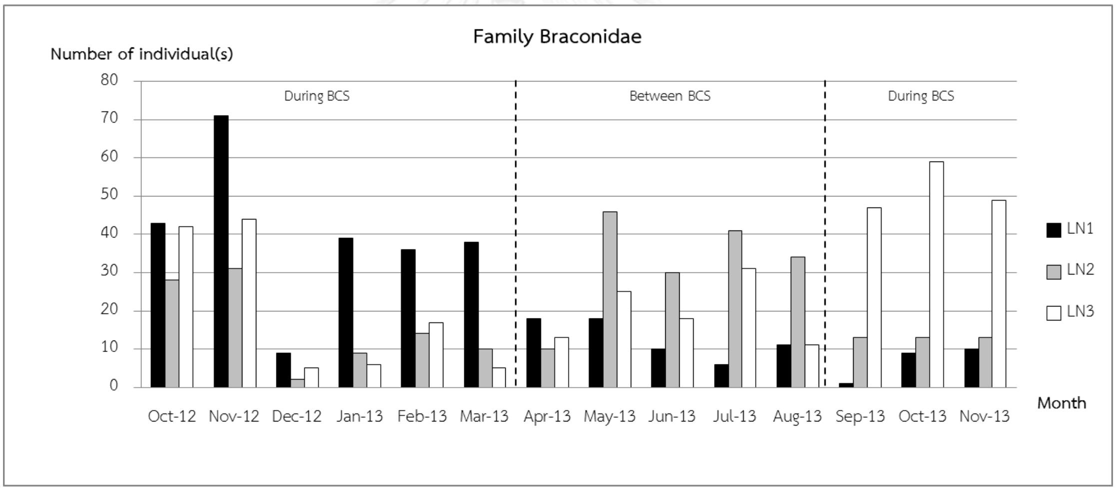

Figure 4-112 Abundance of family Braconidae found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

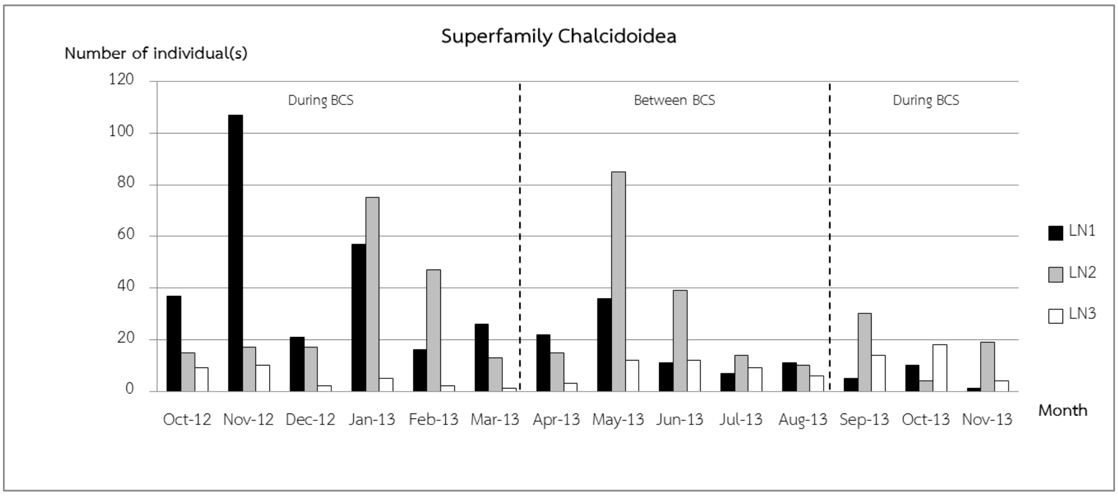

Figure 4-113 Abundance of superfamily Chalcidoidea found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

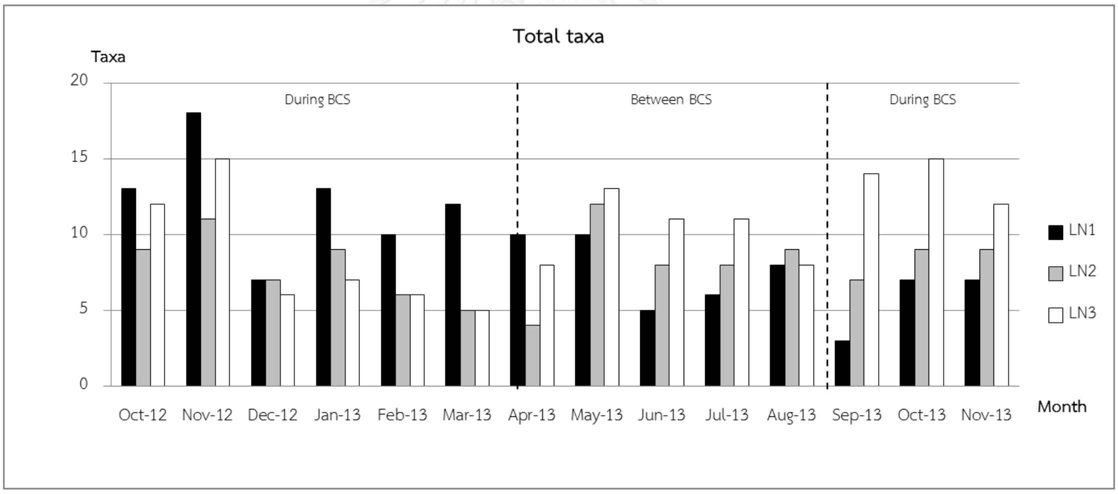

Figure 4-114 Number of total taxa found during and between *Brassica* cultivated seasons (October 2012 - November 2013) and compared among the three study sites at Lainan Subdistrict, Wiang Sa District, Nan Province

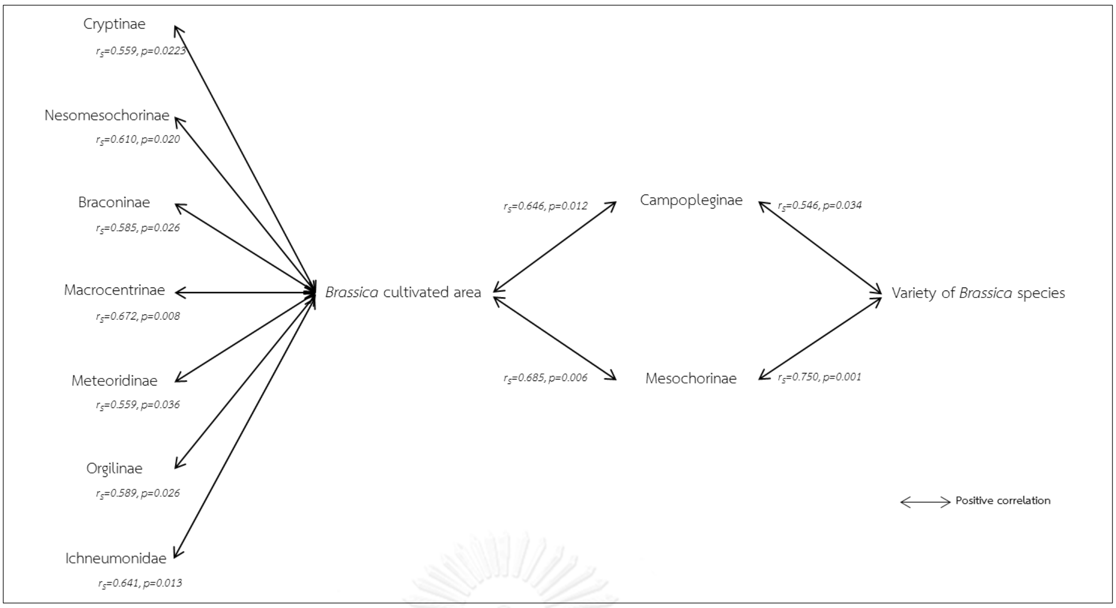

Figure 4-115 Spearman correlations between the *Brassica* cultivation area, variety of *Brassica* species and parasitic wasps taxa (subfamilies Campopleginae; Cryptinae; Mesochorinae; Nesomesochorinae; Braconinae; Macrocentrinae; Meteoridinae; Orgilinae and family Braconidae) during and between *Brassica* cultivated seasons (October 2012 - November 2013)

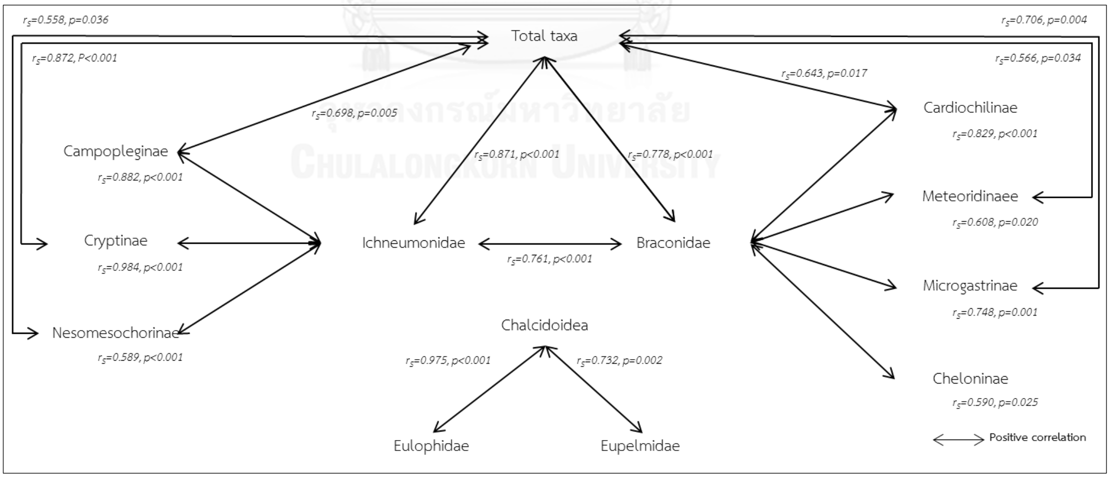

Figure 4-116 Spearman correlations between the family Ichneumonidae, family Braconidae, superfamily Chalcioidea and total taxa of parasitic wasps during and between *Brassica* cultivated seasons (October 2012 - November 2013)

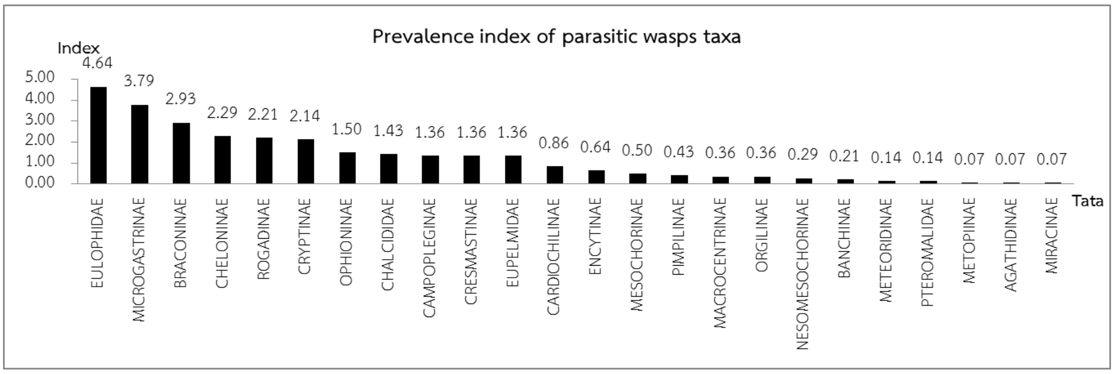

Figure 4-117 Prevalence index of each parasitic wasp taxon during and between *Brassica* cultivated seasons (October 2012 - November 2013)

4.5.2 Other parasitic wasps recorded from four trap samplings

Twenty-four taxa of parasitic wasps were collected from four sampling methods; Malaise trap, mobile bucket light trap, yellow pan trap and aerial net. Different type of traps would collected different groups of parasitic wasps, for example subfamilies Banchinae and Nesomesochorinae were collected by the Malaise trap; subfamily Miracinae was collected using the aerial net; subfamilies Cardiochilinae, Macrocentrinae, Meteoridinae, Ophioninae and Orgilinae were collected by Malaise trap and mobile bucket light trap. The Malaise trap and yellow pan trap were yielded only subfamily Cresmastinae, while family Perilampidae was collected from aerial net and yellow pan trap. Parasitic wasps collected from the three sampling methods; Malaise trap, mobile bucket light trap and aerial net were the subfamily Campopleginae and Malaise trap, aerial net and yellow pan trap were collected the subfamily Mesochorinae, Cryptinae and family Chalcididae. Subfamilies Braconinae, Cheloninae, Microgastrinae, Rogadinae and family Eulophidae were collected from the four sampling methods. In conclusion, Malaise trap was highly effective trap to collect parasitic wasps (22 taxa), while the mobile bucket light trap, aerial net and yellow pan trap collected 11, 16 and 10 taxa, respectively (Figure 4-118).

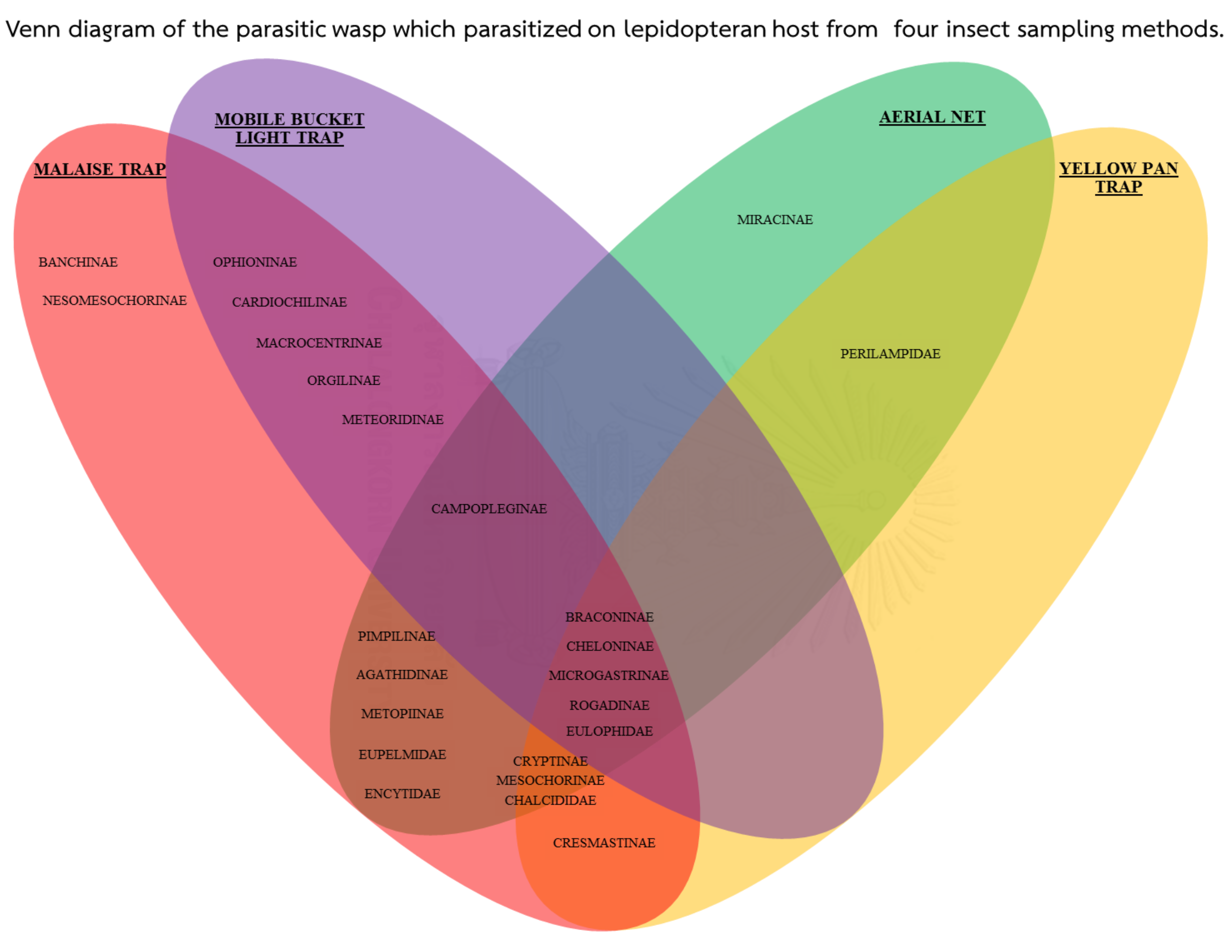

Figure 4-118 Different taxa of parasitic wasps collected from four trap samplings (Malaise trap, mobile bucket light trap, yellow pan trap and aerial net) during and between *Brassica* cultivated seasons (October 2012 - November 2013)

CHAPTER 5
DISCUSSION

Physical factors and *Brassica* cultivation

From the observation in this study, climatic factors were the main reasons for the farmers to decide when to grow *Brassica* crops. The cultivated seasons, normally start in September or October every year when the temperature is low with high humidity which is suitable for *Brassica* crops. During the *Brassica* cultivated seasons, mix *Brassica* crops (cabbage, cauliflower, broccoli, Chinese kale and pak choi) are majority crops (20-80% of growing area) and other vegetables are minority crops which were grown in all the study sites. The *Brassica* cultivated seasons at these localities were similar to other lowland *Brassica* cultivation areas in the Northern part of Thailand. However, most of the previous studies reported the large scale of monocultured landscape of *Brassica* cultivars, while this study location, the areas are rather small (0.08 – 0.24 Ha) with multicultured landscape (Rowell, Jeerakan et al. 1992, Rowell, Bunsong et al. 2005).

Brassica crops and lepidopteran pests

There was no significant difference among the abundance of the nine species of lepidopteran pests (*S. litura*, *P. xylostella*, *P. rapae*, *T. ni*, *H. undalis*, *C. pavonana*, *O. subnotata*, *A. micaceana* and *H. arimgera*) among the study sites. Normally, field management practices could affect to the abundance of insects; however the selective of pesticide used and other field management (irrigation, fertilization, etc.) were not significantly correlated to the insect abundance in this research. The status of major and minor lepidopteran pests had been classified from the abundance and the frequency of pests' larvae and pupae found in the *Brassica* crops. In Southeast Asia, *P. xylostella*, *P. rapae*, *P. brassicae* and *H. undalis* are classified as very important pests (Sivapragasam and Chua 1997). In the other lowland *Brassica* cultivation areas of Chiang Mai Province, *S. litura* and *P. xylostella* are the major lepidopteran pests on the *Brassica* crops (Rowell, Jeerakan et al. 1992). Similar to this study, *S. litura*, *P. xylostella*, *P. rapae* and *T. ni*, were also recorded as the major pests of *Brassica* crops. In broccoli, all nine lepidopteran pest species were found, *S. litura* were the most abundant pests found on broccoli, with 1,019 individuals. For this locality, *S. litura* were the generalist lepidopteran pests, and they had been collected from all *Brassica* species. However, *P. xylostella* and *P. rapae* were highly abundant in cabbages, broccoli and cauliflowers, while *C. pavonana* were mainly found on Chinese kales and pak chois. Different host plants for lepidopteran pests were controlled and limited by the chemical compounds of *Brassica* (glucoside), developmental stages of the host plants, morphology and the use of fertilizers (David and Gardiner 1966, Chew 1977, Myers 1985, Renwick and Radke 1987, Smyth, Hoffmann et al. 2003, Ale, Zalucki et al. 2011).

At during the beginning of *Brassica* cultivated seasons (end of monsoon months – start of the winter), the abundance of *S. litura* was high. Period of *S. litura* outbreaks was influenced by the climatic factors, especially temperature and humidity (Rao, Wightman et al. 1989). In addition, their abundance during the early *Brassica* cultivated seasons of the study location could possibly related to the tobacco plants grown between the *Brassica* cultivated seasons, which serve as the reservoir for *S. litura* when no *Brassica* are grown. Similar to the previous study at Chiang Mai Province, the abundance of *S. litura* was higher at the beginning of *Brassica* cultivated season and decreased at the late of the season. Whereas, the abundance of *P. xylostella* was dominate during February – April in 1990 (Rowell, Jeerakan et al. 1992).

In this study location, the diversity of *Brassica* cultivars were positively correlated to the abundance of *S. litura*. However, the abundance of other lepidopteran pests did not have any correlation to the *Brassica* cultivars and size of the *Brassica* cultivation areas, but showed a positive correlation to the abundance of other species of the lepidopteran pests (*P. xylostella*, *H. undalis*, *P. rapae* and *C. pavonana*). Letourneau (1997) reported that the diversity of landscapes reduced the abundance of phytophagous pests but increased the abundance of parasitoids. The population of parasitoids in this study was similar during the month in which the diversity of pests are low, the variety of *Brassica* cultivars are highly diverse (October 2012 and October 2013).

Lepidopteran pests and beneficial parasitoids

For this study, *S. litura* was parasitized by five parasitic wasps (*Microplitis* sp., *Mesochorus* sp., *Metopius* sp., *Charops* sp. and *Diadegma* sp.) and one parasitic fly (tachinid fly), they are common parasitoids and usually parasitized *S. litura*. In addition to the world checklist of the natural enemies and diseases of *S. litura*, most of *S. litura* parasitoids in this study were also reported except for *Metopius* sp. (Ranga Rao, Wightman et al. 1993). The primary parasitoids, *Microplitis manila* (Ashmead) had been found in Chiang Mai Province as fifteen specimens of *M. manila* were collected from eighteen individuals of *S. litura* in December 1989 (Rowell, Jeerakan et al. 1992). From the study areas, the *Microplitis* sp. usually parasitized *S. litura* and was recorded every month during the *Brassica* cultivated seasons. Their parasitism rate was at the highest in March 2013 with 25% parasitism, while the highest number of *Microplitis* sp. individuals was recorded in December 2013 from 147 individuals (18.9%) of *S. litura*.

The world review of *S. litura*'s natural enemies by Ranga Rao, Wightman et al. (1993) reported many species of *Microplitis* sp. are able to parasitize *S. litura*. For example, *M. demolitor* Wilk, (Australia); *M. pallidipes* Szepl and *M. tuberculifera* (Wesm) (China) and *M. pradiniae* R.S.K. (India). In Thailand, *Microplitis manila*e has been reported not only at Chiang Mai Province, but also export to other countries. They were introduced to control *Spodoptera exigua* in the vegetation area of Malaysia and *Spodoptera frugiperda* in the United States, respectively (Yahaya and Sivapragasam , Rajapakse, Ashley et al. 1985).

The abundance of *Microplitis* sp. was positively correlated to the abundance of *S. litura*. A natural enemy of *Microplitis* sp. was recorded, *Mesochorus* sp., which is a hyperparasitoids of *Microplitis* sp.. *Mesochorus* sp. was recorded in December 2012, January, March and September – November 2013. The highest numbers of *Mesochorus* sp. were 10 individuals in November 2013. In Chiang Mai Province, an unidentified ichneumonid wasp had been reported, it could probably be *Mesochorus* sp. (the relative hyperparasitoids of *Microplitis* sp.) (Rowell, Jeerakan et al. 1992, Ranga Rao, Wightman et al. 1993). The abundance of *Mesochorus* sp. was related to the diversity of beneficial parasitoids species and positively correlated to the total parasitism rates.

Charops sp., *Diadegma* sp. and tachinid fly were reported as the parasitoids of *S. litura* (Ranga Rao, Wightman et al. 1993), but with low parasitism rates in this study locations. The abundance of *Charops* sp. was positively correlated to their host abundance. In addition to the diversity of parasitoids, the total number of parasitoids and the parasitism rate were all positively correlated to the abundance of *Charops* sp., whereas the tachinid fly was positively correlated to the diversity and parasitism rates of parasitoids.

Plutella xylostella was recorded with only a single parasitoid species. *Cotesia plutellae* is an important parasitoids of *P. xylostella* in Thailand with successful parasitism in both lowland and highland of *Brassica* cultivation areas (Keinmeesuke, Vattanatangum et al. 1992, Rowell, Jeerakan et al. 1992, Rowell, Bunsong et al. 2005, Upanisakorn, Jeerapong et al. 2011). Rowell, Jeerakan et al. (1992) reported the parasitism rate of. *C. plutellae* on *P. xylostella* during February 1990 was 44 – 54%, while during 2003-2004, the parasitism rate increased to 78% in the small organic agricultural areas (Rowell, Bunsong et al. 2005). Sow, Diarra et al. (2013) reported the abundance of *P. xylostella* in cabbage cultivation areas at United States was positively correlated to the abundance of *C. plutella* ($r=0.77, p<0.001$). However, there was no positive correlation between the *P. xylostella* and *C. plutellae* in this study.

From this research, *Brachymeria* sp. was one of the natural enemies of *P. rapae*. Burks (1960) reported that this parasitoid also parasitized other lepidopteran pests. In Chiang Mai Province, *Cotesia* (=*Apanteles*) *glomeratus* was recorded with the gregarious parasitoid of *P. brassicae* (Rowell, Jeerakan et al. 1992). On this location location, an unknown gregarious braconid wasp (could be eirher *Cotesia* sp. or *Apanteles* sp.) was recorded with an unsuccessful parasitism on *P. xylostella*. However, there was no significant correlation between the abundance of *P. rapae* and *Brachymeria* sp. in this study location, probably because the low abundance of *P. xylostella* collected.

In this study, *Trathala* sp. showed relative high successful parasitism in *H. undalis* in January, February and March 2013 with 12.5%, 36.4% and 39.1%, respectively. In Cameron Highlands, Malaysia, *H. undalis* was parasitized by *Trathala flavoorbitalis* and *Basus* sp.. However, in the field conditions, the parasitism of *H. undalis* in Malaysia are less than 15% of the parasitism rate (Sivapragasam and Aziz 1992, Sivapragasam and Chua 1997). In addition, the abundance of *H. undalis* in this study was positively correlated to the abundant of *Trathala* sp..

Crocidolomia pavonana was parasitized by *Dolichogenidae* sp., *Therophilus* sp. and *Chelonus* sp.. The abundance of *Dolichogenidae* sp. and *Therophilus* sp. were correlated to the diversity and total number of parasitoids from host rearing methods. *Cotesia* sp. and *Snellius* sp. were recorded on *T. ni*. *Cotesia* sp. was the solitary parasitoids of *P. xylostella* with only an adult emerged from its host. However, *Cotesia* sp. was the gregarious parasitoids of *T. ni*, with 6 adults emerged from a single host. In Southeast Asia, there was no report that the *O. subnotata* attacked the *Brassica* crops. However, an unknown cryptinid wasp was successful parasitizws *O. subnotata* in this locality.

Ives (1992) reported the density of hosts led to the density of parasitoids and parasitism rates. In this study, the diversity and total number of parasitoids from host rearing were positively correlated to the diversity and total number of lepidopteran pests. Parasitism rates were related to the diversity and total number of lepidopteran pests. Laboratory studied by Schooler, Ives et al. (1996) and field experiment by Höller, Borgemeister et al. (1993) suggested that the effect of density of primary parasitoids to the hyperparasitism on aphids was related to the primary parasitoids density dependent and density independent. In this study the abundance of the hyperparasitoids, *Mesochorus* sp. was positively correlated to their primary parasitoids and total parasitism rates. Marino and Landis (1996) reported the diversification of the vegetation landscapes affected the diversity of parasitoids and their parasitized. However, in this study site, there was no relationships of *Brassica* cultivation, diversity of parasitoids and parasitism rates.

Abundance of beneficial parasitic wasps

There was no significant difference on the abundance of thirteen species of beneficial parasitic wasps among the three study sites. The fluctuation of their abundance during and between *Brassica* cultivated seasons can be divided into two groups. First group are *Diadegma* sp., *Charops* sp. and *Chelonus* sp., the abundance was difference among the seasons, while others species were not significantly different on their abundance among the seasons. The abundance of *Charops* sp. was positively correlated to their host (*S. litura*'s abundance) and the size of *Brassica* cultivation area. Similarly, the abundance of *Diadegma* sp. had shown the positive correlation to the abundance of *S. litura*, diversity of *Brassica* cultivars and the size of *Brassica* cultivation area. The abundance of *Diadegma* sp. and *Charops* sp. were significantly different among the seasons and higher during *Brassica* cultivated seasons than between the cultivated seasons. In contrast, the abundance of *Chelonus* sp. was high between the cultivated seasons and was significantly different during the *Brassica* cultivated seasons. However, the abundance of some parasitic wasp species were negatively correlated between host rearing and trap samplings. For *Trathala* sp., size of *Brassica* cultivation area was negatively correlated to the abundance of their host and their numbers in host rearing method. However, the abundance of *Trathala* sp. from the host rearing method was positively correlated to the size of *Brassica* cultivation areas and was negatively correlated to the numbers of *Trathala* sp. in trap samplings.

Hunter (2002) reported the scale of landscape affected the abundance and richness of insects. In this study, there was no significant difference on species richness of the beneficial parasitic wasps in the trap samplings among the seasons. However, the highest diversity indices recorded in November 2013 (during the cultivated season). Diversity of beneficial parasitic wasps in the trap samplings was positively correlated to the size of the *Brassica* cultivation areas and total number of beneficial parasitic wasps in the trap samplings, while the total numbers of parasitoids in host rearing were negatively correlated to the diversity of beneficial parasitic wasps in the trap samplings. This negative correlation between the trap samplings and host rearing was referred to the effect of trap samplings that may disturb the lepidopteran pests and parasitoids interactions reflecting low numbers of host and parasitoid from in host rearing.

Tack and Roslin (2010) reported the neighboring landscape properties serve as reservoir to the phytophagous insects and their natural enemies. In this study, during September and October 2013, numbers of beneficial parasitic wasp species collected from trap samplings in the LN3 site were the highest (175 and 148 individuals, respectively). However, there were no *Brassica* crops growing in this study site during that period. Therefore, the high abundance of beneficial parasitic wasps could be affected by the neighbor landscape which serve as food sources, habitat reservoirs and suitability properties for the alternative hosts or beneficial parasitic wasp abundance (Starý 1993, Landis, Wratten et al. 2000).

Abundance and diversity of other parasitic wasps

Twenty four taxa of parasitic wasps which parasitized lepidopteran hosts were found in this research. There was no significant difference of parasitic wasp abundance among the three study sites, except for the subfamilies Campopleginae, Ophioninae, Orgilinae, Rogadinae and families Eulophidae and Eupelmidae. However, there was no significant difference of parasitoid abundance during and between *Brassica* cultivated seasons. Subfamily Campopleginae was highly abundant during the vegetation seasons in the organic agricultural areas at California, United States (Sow, Diarra et al. 2013). In this study, abundance of the subfamilies Campopleginae (including of genus *Diagegma*, *Charops*, etc.) and Mesochorinae (taxa of hyperparasitoids) were positively correlated to the variety of *Brassica* cultivars and size of *Brassica* cultivation area. Whereas, subfamilies Cryptinae, Nesomesochorinae, Braconinae, Macrocentrinae, Meteoridinae, Orgilinae and family Ichneumonidae were positively correlated to the size of *Brassica* cultivation area.

Complex landscapes shown highly diverse of parasitoids than the simple landscapes, (Richard 1973, Landis, Menalled et al. 2005). During the beginning of *Brassica* cultivated seasons, the diversity of parasitic wasps were highly diverse

(Shannon-Weiner index = 2.20 in October 2012, 2.36 in November 2012 and 2.30 in October 2013), which was the same month with high diversity of *Brassica* cultivars and low diversity of lepidopteran pests. Similar to the previous studies, the scale and diversity of landscapes led to the diversity and abundance of the insect pests and their parasitoids (Letourneau 1997).

In the trap samplings, family Eulophidae showed the highest prevalence index followed by subfamily Microgastrinae (*Microplitis* sp., *Dolichogenidae* sp., *Cotesia* spp. and *Snellius* sp.). The Malaise trap was a highly effective trap to collect parasitic wasps (Marshall 1994, Grootaert, Pollet et al. 2010). In this research, 22 taxa were recorded from Malaise traps, especially subfamily of the families Ichneumonidae and Braconidae, this results similar to the previous studies (Noyes 1989, Idris, Zaneedarwaty et al. 2001). For Nocturnal parasitic wasps, such as subfamilies Ophioninae, Cheloninae and Rogadinae, they are usually collected by mobile bucket light trap, and Malaise trap. In *Brassica* cultivation areas of Sumatra, Indonesia, yellow pan traps were used to sampling adult parasitic wasps, high number of parasitoids in families Ichneumonidae and Braconidae have been recorded from this trap (Yaherwandi 2012). For this study, the yellow pan traps collected only 10 taxa of parasitic wasps, it could probably caused by the limited numbers of yellow pan traps used (only four traps each study site). For the aerial net, 16 taxa collected by netting, which were rather low because aerial net can be only swept above the *Brassica* plants, to prevent the crops damage. Subfamilies Microgastrinae, Braconinae, Cheloninae, Rogadinae and family Eulophidae were collected with a high number from all trap sampling methods, due to their biology, behaviour and diversity.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

Conclusion

Temperature and humidity were the key factors for farmers to decide when to grow *Brassica* crops. During *Brassica* cultivated seasons (October 2012 – March 2013 and September – November 2013), five cultivars of *Brassica* (cabbage, broccoli, cauliflower, Chinese kale and pak choi) and size of *Brassica* cultivation areas served to the diversity and abundance of lepidopteran pests and their parasitoids. *Spodoptera litura*, *P. xylostella*, *P. rapae* and *T. ni* were the major pests of *Brassica* crops. The abundance of *S. litura* was high at the beginning of each *Brassica* cultivated season and positively correlated to the diversity of *Brassica* cultivars, while the abundance of other lepidopteran pests are not positively correlated to the host plants. For pest control, the threshold of pest number per plant should be measured to determine the economic threshold (ET) and economic injury level (EIL) in the future.

Thirteen species of beneficial parasitoids were recorded from rearing of nine lepidopteran pests collected from five cultivars of *Brassica* crops (Figure 6-1). Complexity of host and parasitoid interactions showed that the abundance of lepidopteran hosts influence the diversity and the abundance of their associated parasitoids during *Brassica* cultivated seasons. When population of *S. litura* was high, the number of its major parasitoid, *Microplitis* sp. increased, and showed the range 6.2 – 25% of successful parasitism rates. Diversity and the total number of lepidopteran pests were positively correlated to the diversity and the total number of beneficial parasitoids.

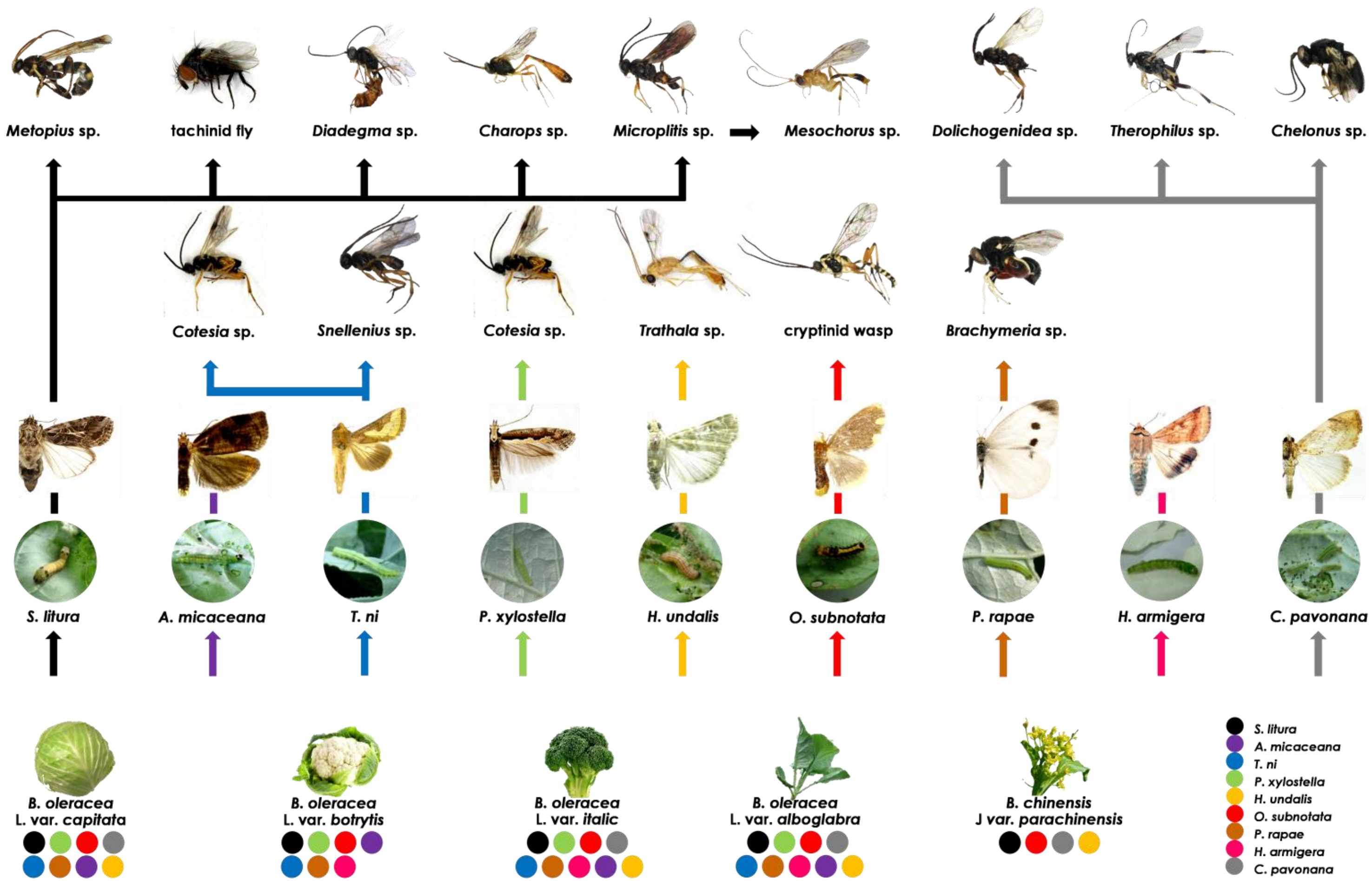

Figure 6-1 Interactions of three trophic levels: *Brassica* crops, lepidopteran pests and beneficial parasitic wasps during *Brassica* cultivation seasons (October 2013–March 2013 and September–November 2013) at Lainan Subdistrict, Wiang Sa District, Nan Province

The diversity and abundance of beneficial parasitic wasps from the host rearing method represented only a snapshot of their information during the cultivated seasons. Malaise traps, mobile bucket light traps, yellow pan traps and aerial net can be combined to monitor the diversity and abundance of the beneficial parasitoids in the study location. The abundance of *Charops* sp. and *Diadegma* sp. was significantly higher during *Brassica* cultivated seasons and was positively correlated to the variety of *Brassica* cultivars and the size of *Brassica* cultivation areas. The abundance of other beneficial parasitoids from the host rearing method was not significantly different during and between *Brassica* cultivated seasons. However, the diversity of the beneficial parasitic wasps in the trap samplings were positively correlated to the *Brassica* cultivation areas, whereas the total number of lepidopteran pests and the beneficial parasitoids in the host rearing were negatively correlated to diversity of beneficial parasitic wasps in the trap samplings. Between *Brassica* cultivated seasons, the lepidopteran pests could shift to the other host plants and parasitoids could attacked the same lepidopteran pests and/or alternative hosts. Therefore, the other alternative lepidopteran hosts and the reservoir plants should be evaluated between the *Brassica* cultivated seasons

The diversity of other parasitic wasps in the trap samplings was not significantly different among the seasons. Twenty four taxa were collected by four sampling methods. During the *Brassica* cultivated seasons, the abundance of Cryptinae, Nesomesochorinae, Braconinae, Macrocentrinae, Meteoridinae, Orgilinae and Ichneumonidae were positively correlated to the size of *Brassica* cultivation areas. Campopleginae and Mesochrinae were positively correlated to both size of *Brassica* cultivation areas and variety of *Brassica* cultivars. Subfamily Microgastrinae (genera *Microplitis* sp., *Dolichogenidae* sp., *Cotesia* spp. and *Snellius* sp.) were usually recorded from all sampling methods, and they showed highly parasitism on the lepidopteran pests in the host rearing experiment. In trap samplings, their abundance was not significantly different among the seasons, and the highest number of individuals were collected by the Malaise trap.

Diversification of plantation and scale of cultivation area influenced to the diversity and abundance of lepidopteran pests and also their parasitoids. Then, for the conservation of beneficial parasitoids in this area, farmers should carefully decoed the proportion and diversity of the *Brassica* crops and other vegetables cultivation. Host rearing method is the first technique to classify the beneficial parasitoids. Malaise traps were able to record the abundance of beneficial parasitoids throughout the year. However, farmers should removed lepidopteran pests (in case of over economic injury level and economic threshold) from the plants, but they should not killed all of them to allow the beneficial parasitoids to survive in the field.

In the future, host and parasitoid interactions should be observed and experimated between the *Brassica* cultivated seasons. Alternative hosts of both lepidopteran pests and parasitoids should be identified and factors influencing the abundance and diversity of parasitoids between the *Brassica* cultivated seasons should be studied. Not only lepidopteran pests, the other phytophagous pest (aphids, flea beetle, sawfly and etc.) and their natural enemies are also found in this study and it is very interestingly to study their interactions in the future. Moreover, the information of *Brassica* crops, lepidopteran pests and beneficial parasitoids should be conducted on highlands of Nan Province to comparison and discussion with this lowland of *Brassica* cultivation areas and other *Brassica* cultivation areas in the Northern of Thailand.

As mentioned above, this research studied the species diversity and interactions of lepidopteran pests and their associated parasitoids on *Brassica* crops during *Brassica* cultivated seasons. Measuring the abundance of beneficial parasitic wasps during and between cultivated seasons and evaluated diversity of beneficial and other parasitic wasps by trap samplings in the *Brassica* agricultural area.

Recommendations

<u>Interested topics for future works</u>

I. Economic injury level (EIL) and Economic threshold (ET) of the lepidopteran pests could be evaluated for measuring and classifing the status of lepidopteran pests and compared to the previous studies.

II. Between *Brassica* cultivated season, other vegetables and crops should be studied their effect to the diversity and abundance of beneficial parasitoids. For lepidopteran pests, there are no information of their alternative host between the *Brassica* cultivated seasons, which suitable for their associated parasitoids.

III. The other tritrophic interactions of *Brassica* crops, other phytophagous pests (aphids, flea beetles, sawfly, etc.) and their parasitoids should be evaluated on their interactions, diversity and abundant in the *Brassica* agricultural areas.

IV. Other highland of *Brassica* cultivation areas of Nan Province are interesting localities to measure the diversity, abundant and interaction between lepidopteran pests and their associated parasitoids for the complete information of pest and parasitoids interactions in both lowland and highland of *Brassica* cultivation area in Nan Province.

<u>Suggestion for farmers</u>

I. For planting, farmers should grow diverse plant with mix crops. During *Brassica* cultivated seasons, farmers should grow with the variety of *Brassica* cultivars and other vegetables. Between *Brassica* cultivated seasons, plants which serve as food source and habitat reservoir to the pests and parasitoids should be cultivated for the alternative hosts or beneficial parasitic wasp abundance.

II. For pest controls, there are no significant difference of parasitic wasp abundance among the three study sites which had different field management and pest controls. Therefore, they should combine the pest control stratergies, integrated pest management (IPM), to conserve the population of parasitic wasps in this locality.

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APPENDICIES

APPENDIX A

Table A-1 Average temperature and humidity from field recorded and average temperature, precipitation and wind speed recorded by Thai Meteorological Department (Nan Provincial Agricultural Extension Office Station) during October 2012 – November 2013.

Month	Field data		Thai Meteorological Department data		
	Average Temperature (°C)	Average Humidity (%)	TMD Average Temperature (°C)	TMD Precipitation (mm^3)	TMD Wind (Knots)
Oct-12	30.4	74.7	28.5	34.3	3
Nov-12	30.3	72.3	27.85	37.4	3
Dec-12	22.7	74.8	25	-	2
Jan-13	24.1	57.3	23.7	38.5	3
Feb-13	28.2	58.7	26.75	5.6	3.2
Mar-13	25	53.3	27.65	12.6	4.1
Apr-13	31.1	52.5	31.3	13.9	4.4
May-13	32.4	55.5	31.35	72.2	7.7
Jun-13	31.7	53.8	29.4	165.2	5.3
Jul-13	29.8	61.8	33	106.7	4.5
Aug-13	29.8	65.2	28.4	224.7	4.1
Sep-13	29.9	54.5	28.15	281.1	4.6
Oct-13	28.9	70	26.8	73.2	3.4
Nov-13	30	71.5	26.5	37.4	3.4

APPENDIX B

Table B-1 Lepidopteran pests of LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	*S. litura*	*P. xylostella*	*P. rapae*	*H. undalis*	*C. pavonana*	*A. micaceana*	*T. ni*	*O. subnotata*	*H. armigera*	No. of Lepidopteran pests species	Total number of lepidopteran pests
Oct-12	95	0	0	0	0	0	0	0	0	1	95
Nov-12	13	2	1	0	0	0	6	0	0	4	22
Dec-12	18	0	0	0	0	0	5	0	0	2	23
Jan-13	4	15	18	0	0	0	0	0	0	3	37
Feb-13	3	13	10	0	0	0	2	0	0	4	28
Mar-13	5	27	49	3	0	0	2	0	0	5	86
Apr-13	-	-	-	-	-	-	-	-	-	-	-
May-13	-	-	-	-	-	-	-	-	-	-	-
Jun-13	-	-	-	-	-	-	-	-	-	-	-
Jul-13	-	-	-	-	-	-	-	-	-	-	-
Aug-13	-	-	-	-	-	-	-	-	-	-	-
Sep-13	13	1	0	0	0	0	0	21	0	3	35
Oct-13	729	4	0	0	0	2	14	5	1	6	755
Nov-13	21	42	1	0	0	0	5	15	0	5	84

Table B-2 Lepidopteran pests of LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	*S. litura*	*P. xylostella*	*P. rapae*	*H. undalis*	*C. pavonana*	*A. micaceana*	*T. ni*	*O. subnotata*	*H. armigera*	No. of Lepidopteran pests species	Total number of lepidopteran pests
Oct-12	35	0	0	0	0	0	0	0	0	1	35
Nov-12	8	1	1	0	0	0	8	1	0	5	19
Dec-12	5	0	0	1	0	34	6	0	0	4	46
Jan-13	65	7	32	0	0	0	12	0	0	4	116
Feb-13	23	24	28	2	0	16	24	0	0	6	117
Mar-13	7	15	42	20	0	0	11	1	0	6	96
Apr-13	-	-	-	-	-	-	-	-	-	-	-
May-13	-	-	-	-	-	-	-	-	-	-	-
Jun-13	-	-	-	-	-	-	-	-	-	-	-
Jul-13	-	-	-	-	-	-	-	-	-	-	-
Aug-13	-	-	-	-	-	-	-	-	-	-	-
Sep-13	10	0	0	0	0	0	5	0	0	2	15
Oct-13	50	1	0	1	73	1	2	68	4	8	200
Nov-13	85	24	4	8	125	2	2	1	0	8	251

Table B-3 Lepidopteran pests of LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	*S. litura*	*P. xylostella*	*P. rapae*	*H. undalis*	*C. pavonana*	*A. micaceana*	*T. ni*	*O. subnotata*	*H. armigera*	No. of Lepidopteran pests species	Total number of lepidopteran pests
Oct-12	0	0	0	0	0	0	0	0	0	0	0
Nov-12	14	0	1	0	0	2	17	1	0	5	35
Dec-12	35	1	0	2	0	1	0	0	0	4	39
Jan-13	3	0	1	8	1	0	0	0	0	4	13
Feb-13	6	12	42	31	1	0	1	0	0	6	93
Mar-13	0	0	0	0	0	0	0	0	0	0	0
Apr-13	-	-	-	-	-	-	-	-	-	-	-
May-13	-	-	-	-	-	-	-	-	-	-	-
Jun-13	-	-	-	-	-	-	-	-	-	-	-
Jul-13	-	-	-	-	-	-	-	-	-	-	-
Aug-13	-	-	-	-	-	-	-	-	-	-	-
Sep-13	0	0	0	0	0	0	0	0	0	0	0
Oct-13	0	0	0	0	0	0	0	0	0	0	0
Nov-13	122	4	1	0	30	0	1	0	0	5	163

APPENDIX C

Table C-1 Beneficial parasitoids from host rearing method (HR) of LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	HR *Microplitis* sp.	HR *Mesochorus* sp.	HR *Diadegma* sp.	HR *Charops* sp.	HR *Metopius* sp.	HR *Tachinid* fly	HR *Dolichogenidae* sp.	HR *Therophilus* sp.	HR *Chelonus* sp.	HR *Cotesia* sp.	HR *Snellius* sp.	HR *Trathala* sp.	HR Cryptinid wasp	HR *Brachymeria* sp.
Oct-12	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov-12	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb-13	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Mar-13	1	0	0	0	0	0	0	0	0	0	0	1	0	5
Apr-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jun-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jul-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sep-13	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct-13	126	6	0	0	0	1	0	0	0	1	0	0	0	0
Nov-13	2	0	0	0	0	0	0	0	0	0	0	0	1	0

Table C-2 Numbers of species, total numbers and parasitism rates of beneficial parasitoids from host rearing method (HR) of LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	No. of HR Parasitoids species	Total number of HR Parasitoids	TOTAL Parasitism rates (%)
Oct-12	1	1	1.1
Nov-12	1	1	4.5
Dec-12	0	0	0.0
Jan-13	0	0	0.0
Feb-13	1	2	7.1
Mar-13	3	7	8.1
Apr-13	-	-	-
May-13	-	-	-
Jun-13	-	-	-
Jul-13	-	-	-
Aug-13	-	-	-
Sep-13	1	2	5.7
Oct-13	4	134	17.7
Nov-13	2	3	3.6

Table C-3 Beneficial parasitoids from host rearing method (HR) of LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	HR *Microplitis* sp.	HR *Mesochorus* sp.	HR *Diadegma* sp.	HR *Charops* sp.	HR *Metopius* sp.	HR *Tachinid* fly	HR *Dolichogenidae* sp.	HR *Therophilus* sp.	HR *Chelonus* sp.	HR *Cotesia* sp.	HR *Snellius* sp.	HR *Trathala* sp.	HR Cryptinid wasp	HR *Brachymeria* sp.
Oct-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov-12	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec-12	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan-13	7	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb-13	1	0	0	0	0	0	0	0	0	3	0	0	0	0
Mar-13	2	1	0	0	0	0	0	0	0	2	0	8	0	2
Apr-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jun-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jul-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sep-13	0	2	0	0	0	0	0	0	0	0	1	0	0	0
Oct-13	11	2	1	5	0	0	3	11	0	0	0	0	0	0
Nov-13	9	4	0	1	0	1	0	12	1	0	0	0	0	0

Table C-4 Numbers of species, total numbers and parasitism rates of beneficial parasitoids from host rearing method (HR) of LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	No. of HR Parasitoids species	Total number of HR Parasitoids	TOTAL Parasitism rates (%)
Oct-12	0	0	0.0
Nov-12	1	2	10.5
Dec-12	1	1	2.2
Jan-13	1	7	6.0
Feb-13	2	4	3.4
Mar-13	5	15	15.6
Apr-13	-	-	-
May-13	-	-	-
Jun-13	-	-	-
Jul-13	-	-	-
Aug-13	-	-	-
Sep-13	2	3	20.0
Oct-13	6	33	16.5
Nov-13	6	28	11.2

Table C-5 Beneficial parasitoids from host rearing method (HR) of LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	HR *Microplitis* sp.	HR *Mesochorus* sp.	HR *Diadegma* sp.	HR *Charops* sp.	HR *Metopius* sp.	HR *Tachinid* fly	HR *Dolichogenidae* sp.	HR *Therophilus* sp.	HR *Chelonus* sp.	HR *Cotesia* sp.	HR *Snellius* sp.	HR *Trathala* sp.	HR Cryptinid wasp	HR *Brachymeria* sp.
Oct-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov-12	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec-12	5	3	0	0	1	1	0	0	0	0	0	0	0	0
Jan-13	4	1	0	0	0	0	0	1	0	0	0	1	0	0
Feb-13	2	0	0	0	0	0	0	0	0	0	0	12	0	0
Mar-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jun-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jul-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sep-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov-13	30	6	0	1	0	0	0	8	0	0	0	0	0	0

Table C-6 Numbers of species, total numbers and parasitism rates of beneficial parasitoids from host rearing method (HR) of LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	No. of HR Parasitoids species	Total number of HR Parasitoids	TOTAL Parasitism rates (%)
Oct-12	0	0	0.00
Nov-12	1	1	2.86
Dec-12	4	10	25.64
Jan-13	4	7	53.85
Feb-13	2	14	15.05
Mar-13	0	0	0.00
Apr-13	-	-	-
May-13	-	-	-
Jun-13	-	-	-
Jul-13	-	-	-
Aug-13	-	-	-
Sep-13	0	0	0.00
Oct-13	0	0	0.00
Nov-13	4	45	27.61

APPENDIX D

Table D-1 Beneficial parasitoids from forus trap sampling methods (Trap) of LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Trap *Microplitis* sp.	Trap *Mesochorus* sp.	Trap *Diadegma* sp.	Trap *Charops* sp.	Trap *Metopius* sp.	Trap *Tachinid* fly	Trap *Dolichogenidae* sp.	Trap *Therophilus* sp.	Trap *Chelonus* sp.	Trap *Cotesia* sp.	Trap *Snellius* sp.	Trap *Trathala* sp.	Trap Cryptinid wasp	Trap *Brachymeria* sp.	No. of Trap Parasitoids species	Total number of Trap Parasitoids
Oct-12	6	0	5	0	0	12	0	7	7	2	2	0	1	8	42	6
Nov-12	2	4	2	1	2	12	0	13	7	0	4	0	1	10	48	2
Dec-12	3	1	2	1	2	15	0	9	16	1	5	0	0	10	55	3
Jan-13	22	0	6	3	2	24	0	17	29	1	8	1	0	10	113	22
Feb-13	13	0	1	3	1	11	0	13	22	1	6	0	0	9	71	13
Mar-13	6	0	2	1	0	19	1	7	17	0	0	0	0	7	53	6
Apr-13	0	0	1	0	0	19	0	10	2	0	5	0	0	5	37	0
May-13	3	0	0	1	1	4	0	12	3	1	5	0	0	8	30	3
Jun-13	1	0	1	0	0	0	0	10	0	0	0	0	0	3	12	1
Jul-13	1	0	0	0	0	1	0	0	4	0	0	0	0	3	6	1
Aug-13	0	0	0	0	0	1	0	0	1	1	0	0	0	3	3	0
Sep-13	0	0	0	0	0	1	0	0	3	0	0	0	0	2	4	0
Oct-13	0	1	0	0	0	0	0	1	0	0	0	0	0	2	2	0
Nov-13	2	0	0	0	0	0	0	0	1	0	0	0	0	2	3	2

Table D-2 Beneficial parasitoids from forus trap sampling methods (Trap) of LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Trap *Microplitis* sp.	Trap *Mesochorus* sp.	Trap *Diadegma* sp.	Trap *Charops* sp.	Trap *Metopius* sp.	Trap *Tachinid* fly	Trap *Dolichogenidae* sp.	Trap *Therophilus* sp.	Trap *Chelonus* sp.	Trap *Cotesia* sp.	Trap *Snellius* sp.	Trap *Trathala* sp.	Trap Cryptinid wasp	Trap *Brachymeria* sp.	No. of Trap Parasitoids species	Total number of Trap Parasitoids
Oct-12	12	0	7	2	0	17	0	3	19	1	2	0	0	8	63	12
Nov-12	0	2	2	3	0	33	0	11	10	0	18	0	1	8	80	0
Dec-12	1	0	0	2	1	9	0	5	6	0	5	0	0	7	29	1
Jan-13	2	0	4	0	0	2	0	0	2	0	2	0	0	5	12	2
Feb-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mar-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apr-13	2	0	5	0	0	8	0	4	6	0	1	0	0	6	26	2
May-13	2	0	2	0	0	52	0	34	8	1	5	0	2	8	106	2
Jun-13	2	0	2	0	0	26	0	8	10	0	0	0	0	5	48	2
Jul-13	3	0	4	0	0	44	0	15	25	0	11	0	0	6	102	3
Aug-13	2	0	1	0	0	8	0	3	29	0	4	0	0	6	47	2
Sep-13	2	0	1	0	0	3	0	0	9	0	1	0	0	5	16	2
Oct-13	0	0	2	2	0	2	0	0	13	0	3	0	1	6	23	0
Nov-13	5	1	2	1	0	6	0	0	8	1	2	0	0	8	26	5

Table D-3 Beneficial parasitoids from forus trap sampling methods (Trap) of LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Trap *Microplitis* sp.	Trap *Mesochorus* sp.	Trap *Diadegma* sp.	Trap *Charops* sp.	Trap *Metopius* sp.	Trap *Tachinid* fly	Trap *Dolichogenidae* sp.	Trap *Therophilus* sp.	Trap *Chelonus* sp.	Trap *Cotesia* sp.	Trap *Snellius* sp.	Trap *Trathala* sp.	Trap Cryptinid wasp	Trap *Brachymeria* sp.	No. of Trap Parasitoids species	Total number of Trap Parasitoids
Oct-12	3	0	4	4	0	29	0	5	7	3	4	1	2	10	62	3
Nov-12	3	1	3	0	2	21	0	5	9	0	1	0	0	8	45	3
Dec-12	0	1	0	2	2	13	1	2	7	0	0	0	0	7	28	0
Jan-13	1	0	1	0	0	3	0	2	3	0	1	0	0	6	11	1
Feb-13	1	0	1	0	0	2	0	1	2	0	1	0	0	6	8	1
Mar-13	5	0	0	1	0	5	0	1	7	0	4	0	0	6	23	5
Apr-13	4	0	2	2	1	25	0	34	15	0	2	1	0	9	86	4
May-13	2	0	1	1	0	24	0	14	10	0	5	0	0	7	57	2
Jun-13	4	1	3	1	0	5	0	12	4	0	3	0	0	8	33	4
Jul-13	4	0	1	3	0	6	0	13	12	0	0	0	0	6	39	4
Aug-13	19	0	1	0	0	10	0	8	9	0	1	0	0	6	48	19
Sep-13	36	2	16	2	1	46	0	15	36	0	18	2	1	11	175	36
Oct-13	16	0	31	3	0	31	0	25	18	2	21	0	1	9	148	16
Nov-13	10	2	19	2	0	40	0	11	20	1	29	1	0	10	135	10

APPENDIX E

Table E-1 Other parasitic wasps (1) from forus trap sampling methods of LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Banchinae	Campopleginidae	Cresmastinae	Cryptinae	Mesochorinae	Nesomesochorinae	Ophionidae	Pimpilinae	Metopiinae
Oct-12	0	1	1	3	0	0	3	0	0
Nov-12	0	1	2	5	1	0	12	1	0
Dec-12	0	0	1	0	1	0	3	0	0
Jan-13	1	4	5	5	1	1	0	0	0
Feb-13	0	0	2	2	0	0	0	0	0
Mar-13	1	1	0	4	0	0	3	0	0
Apr-13	0	0	3	2	0	0	0	0	0
May-13	0	0	0	5	0	0	2	0	0
Jun-13	0	0	0	2	0	0	0	0	0
Jul-13	0	0	0	1	0	0	0	0	0
Aug-13	0	0	0	0	0	0	0	0	0
Sep-13	0	0	0	1	0	0	0	0	0
Oct-13	0	0	0	1	1	0	0	0	0
Nov-13	0	0	0	1	2	0	0	0	0

Table E-2 Other parasitic wasps (2) from forus trap sampling methods of LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Agathinidae	Braconidae	Cardiochilinae	Macrocentrinae	Meteoridinae	Microgastrinae	Orgilinae	Rogadinae	Miracinae	Cheloninae
Oct-12	0	13	5	0	0	18	0	3	0	4
Nov-12	0	21	19	5	1	15	3	1	0	6
Dec-12	0	2	0	0	0	7	0	0	0	0
Jan-13	0	10	0	0	0	20	2	0	0	7
Feb-13	0	10	1	0	0	6	0	9	0	10
Mar-13	0	13	0	0	0	21	1	3	0	0
Apr-13	0	10	0	0	0	4	0	2	0	2
May-13	0	2	1	0	0	2	0	1	0	12
Jun-13	0	0	0	0	0	1	0	0	0	9
Jul-13	0	1	1	0	0	4	0	0	0	0
Aug-13	0	4	1	0	0	3	0	2	0	1
Sep-13	0	1	0	0	0	0	0	0	0	0
Oct-13	0	3	0	0	0	1	0	4	0	1
Nov-13	0	4	0	1	0	0	2	3	0	0

Table E-3 Other parasitic wasps (3) from forus trap sampling methods of LN1 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Chalcididae	Encytinae	Eulophidae	Eupelmidae	Perilampidae	Ichneumonidae	Braconidae	Chalcidoidea	Total taxa
Oct-12	1	2	26	8	0	8	43	37	13
Nov-12	1	13	81	12	0	22	71	107	18
Dec-12	0	0	20	1	0	5	9	21	7
Jan-13	1	0	53	3	0	17	39	57	13
Feb-13	0	0	12	3	1	4	36	16	10
Mar-13	2	2	16	6	0	9	38	26	12
Apr-13	5	2	11	4	0	5	18	22	10
May-13	1	0	33	2	0	7	18	36	10
Jun-13	0	0	10	1	0	2	10	11	5
Jul-13	1	0	6	0	0	1	6	7	6
Aug-13	1	0	9	1	0	0	11	11	8
Sep-13	0	0	5	0	0	1	1	5	3
Oct-13	0	0	10	0	0	2	9	10	7
Nov-13	0	0	1	0	0	3	10	1	7

Table E-4 Other parasitic wasps (1) from forus trap sampling methods of LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Banchinae	Campopleginidae	Cresmastinae	Cryptinae	Mesochorinae	Nesomesochorinae	Ophionidae	Pimpilinae	Metopiinae
Oct-12	1	2	0	1	0	0	0	0	0
Nov-12	0	2	0	5	3	0	5	1	0
Dec-12	0	1	0	2	0	0	1	0	0
Jan-13	0	2	1	6	0	0	0	0	0
Feb-13	0	0	0	0	0	0	1	0	0
Mar-13	0	0	0	0	0	0	1	0	0
Apr-13	0	0	0	0	0	0	0	0	0
May-13	0	1	1	4	0	0	1	1	2
Jun-13	0	0	1	1	0	0	0	0	0
Jul-13	0	3	2	2	0	0	0	0	0
Aug-13	0	0	1	0	0	0	1	1	0
Sep-13	0	0	0	1	0	0	0	0	0
Oct-13	0	1	1	1	0	0	0	0	0
Nov-13	0	2	1	2	1	0	0	0	0

Table E-5 Other parasitic wasps (2) from forus trap sampling methods of LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Agathinidae	Braconidae	Cardiochilinae	Macrocentrinae	Meteoridinae	Microgastrinae	Orgilinae	Rogadinae	Miracinae	Cheloninae
Oct-12	0	16	0	0	0	8	0	2	0	0
Nov-12	0	11	5	0	0	14	0	0	0	1
Dec-12	0	2	0	0	0	0	0	0	0	0
Jan-13	0	3	0	0	0	5	0	0	0	1
Feb-13	0	7	0	0	0	4	0	3	0	0
Mar-13	0	8	0	0	0	1	0	1	0	0
Apr-13	0	6	0	0	0	2	0	2	0	0
May-13	0	4	0	0	0	21	0	2	1	18
Jun-13	0	5	0	0	0	12	0	1	0	12
Jul-13	0	2	0	0	0	24	0	0	0	15
Aug-13	0	3	0	0	0	26	0	4	0	1
Sep-13	0	5	0	0	0	7	0	1	0	0
Oct-13	0	2	1	0	0	5	0	3	0	2
Nov-13	0	3	0	0	0	5	0	5	0	0

Table E-6 Other parasitic wasps (3) from forus trap sampling methods of LN2 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Chalcididae	Encytinae	Eulophidae	Eupelmidae	Perilampidae	Ichneumonidae	Braconidae	Chalcidoidea	Total taxa
Oct-12	0	0	13	2	0	4	28	15	9
Nov-12	3	0	14	0	0	16	31	17	11
Dec-12	0	1	15	1	0	4	2	17	7
Jan-13	1	0	72	2	0	9	9	75	9
Feb-13	0	1	46	0	0	1	14	47	6
Mar-13	0	0	13	0	0	1	10	13	5
Apr-13	0	0	15	0	0	0	10	15	4
May-13	0	0	85	0	0	10	46	85	12
Jun-13	1	0	38	0	0	2	30	39	8
Jul-13	8	0	6	0	0	7	41	14	8
Aug-13	0	0	9	1	0	3	34	10	9
Sep-13	1	0	27	2	0	1	13	30	7
Oct-13	0	0	4	0	0	3	13	4	9
Nov-13	2	0	17	0	0	6	13	19	9

Table E-7 Other parasitic wasps (1) from forus trap sampling methods of LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

Month	Banchinae	Campopleginidae	Cresmastinae	Cryptinae	Mesochorinae	Nesomesochorinae	Ophionidae	Pimpilinae	Metopiinae
Oct-12	0	6	1	7	0	0	6	0	0
Nov-12	0	4	0	14	1	1	11	2	0
Dec-12	0	0	0	1	0	0	1	0	0
Jan-13	0	1	0	0	0	0	1	0	0
Feb-13	0	0	0	0	0	0	2	0	0
Mar-13	0	1	0	0	0	0	1	0	0
Apr-13	0	0	0	0	0	0	1	0	0
May-13	0	1	4	2	0	0	2	3	0
Jun-13	0	1	3	1	0	0	3	0	0
Jul-13	0	4	0	1	0	0	1	0	0
Aug-13	0	0	0	1	0	0	1	0	0
Sep-13	0	4	6	5	0	1	3	1	0
Oct-13	0	19	10	9	1	1	1	0	0
Nov-13	0	2	1	7	3	0	2	0	0

Table E-8 Other parasitic wasps (2) from forus trap sampling methods of LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

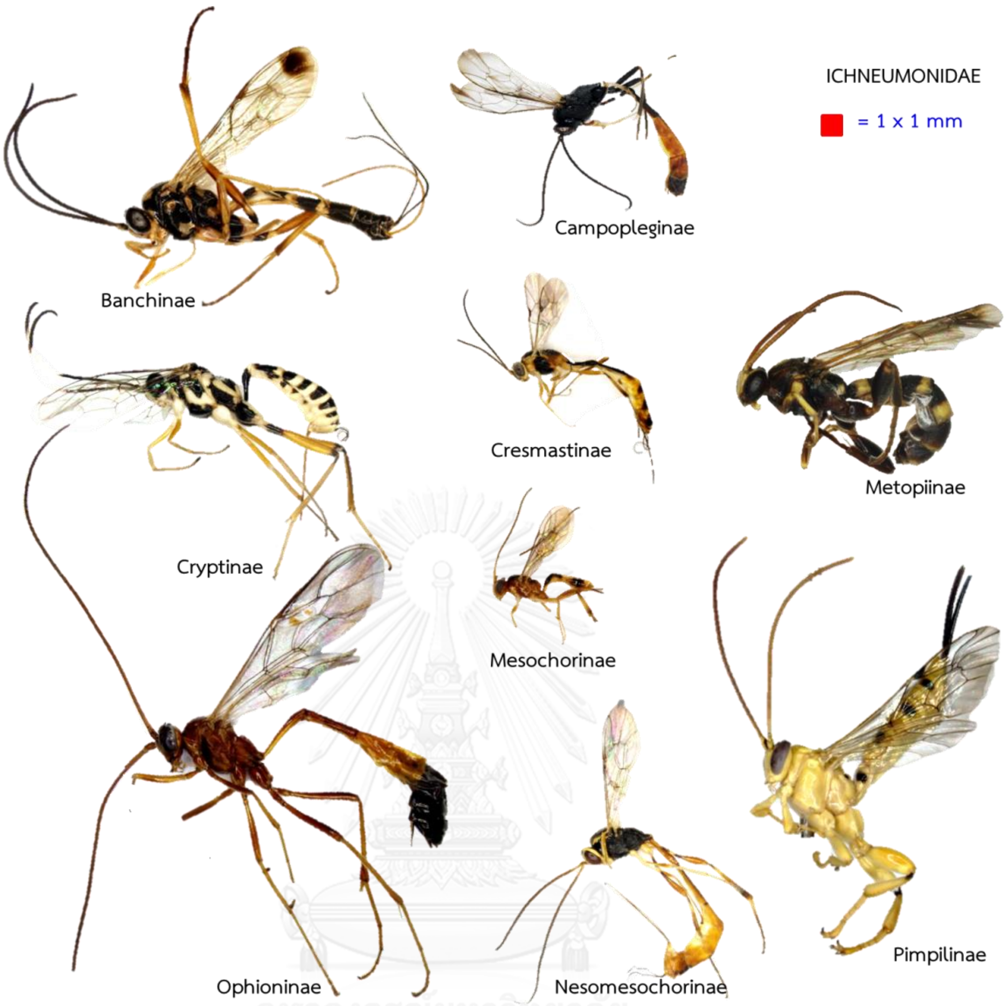
Month	Agathinidae	Braconidae	Cardiochilinae	Macrocentrinae	Meteoridinae	Microgastrinae	Orgilinae	Rogadinae	Miracinae	Cheloninae
Oct-12	0	11	1	0	1	14	0	11	0	4
Nov-12	0	8	9	3	0	14	0	6	0	4
Dec-12	0	2	0	0	0	1	0	2	0	0
Jan-13	0	0	0	0	0	3	0	3	0	0
Feb-13	0	8	0	0	0	2	0	3	0	4
Mar-13	0	3	0	0	0	2	0	0	0	0
Apr-13	0	2	0	0	0	1	0	7	0	3
May-13	1	0	0	0	0	7	0	1	0	16
Jun-13	0	1	0	0	0	5	0	2	0	10
Jul-13	0	2	1	0	0	13	0	8	0	7
Aug-13	0	1	0	0	0	1	0	5	0	4
Sep-13	0	5	1	0	0	35	0	3	0	3
Oct-13	0	7	2	1	0	27	1	7	0	14
Nov-13	0	6	0	3	0	32	0	6	0	2

Table E-9 Other parasitic wasps (3) from forus trap sampling methods of LN3 site, Lainan Subdistrict, Wiang Sa District, Nan Province during and between *Brassica* cultivated seasons (October 2012 – November 2013)

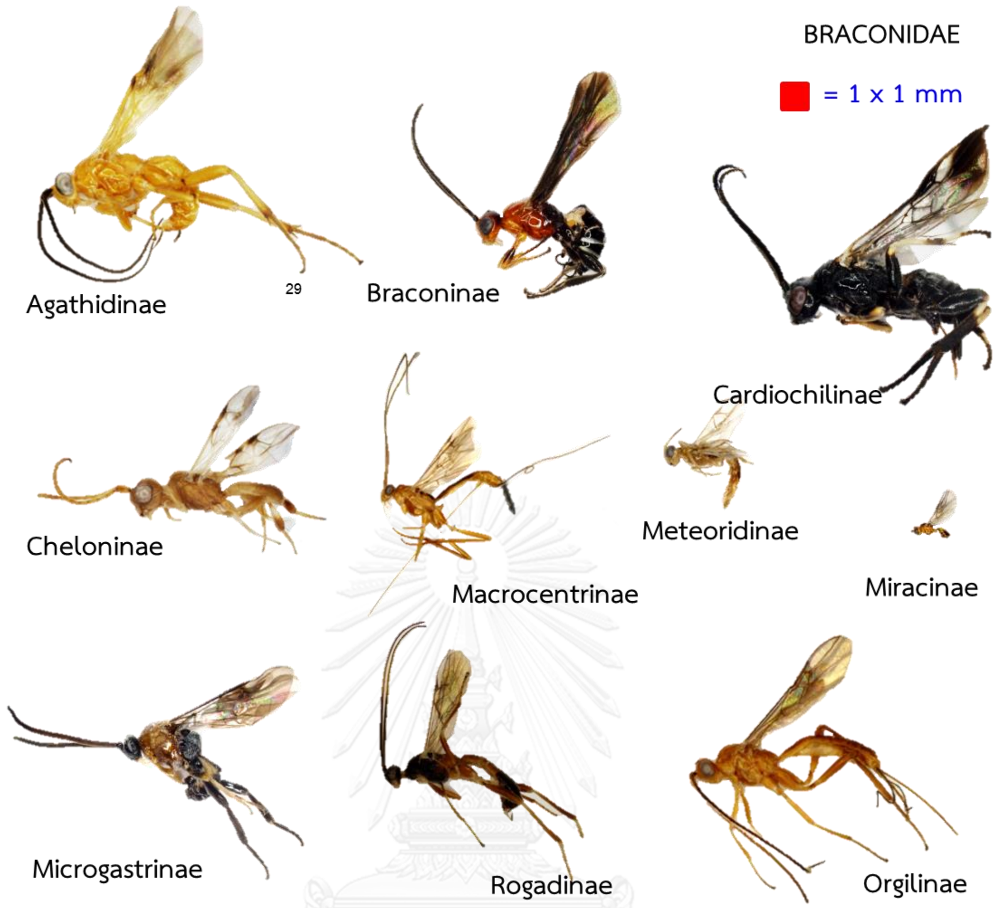
Month	Chalcididae	Encytinae	Eulophidae	Eupelmidae	Perilampidae	Ichneumonidae	Braconidae	Chalcidoidea	Total taxa
Oct-12	2	0	7	0	0	20	42	9	12
Nov-12	2	0	7	0	1	33	44	10	15
Dec-12	0	0	2	0	0	2	5	2	6
Jan-13	2	0	2	1	0	2	6	5	7
Feb-13	0	0	2	0	0	2	17	2	6
Mar-13	0	0	1	0	0	2	5	1	5
Apr-13	1	1	1	0	0	1	13	3	8
May-13	5	2	2	3	0	12	25	12	13
Jun-13	5	0	6	1	0	8	18	12	11
Jul-13	3	0	5	1	0	6	31	9	11
Aug-13	1	0	5	0	0	2	11	6	8
Sep-13	1	0	12	1	0	20	47	14	14
Oct-13	9	0	9	0	0	41	59	18	15
Nov-13	1	0	3	0	0	15	49	4	12

APPENDIX F

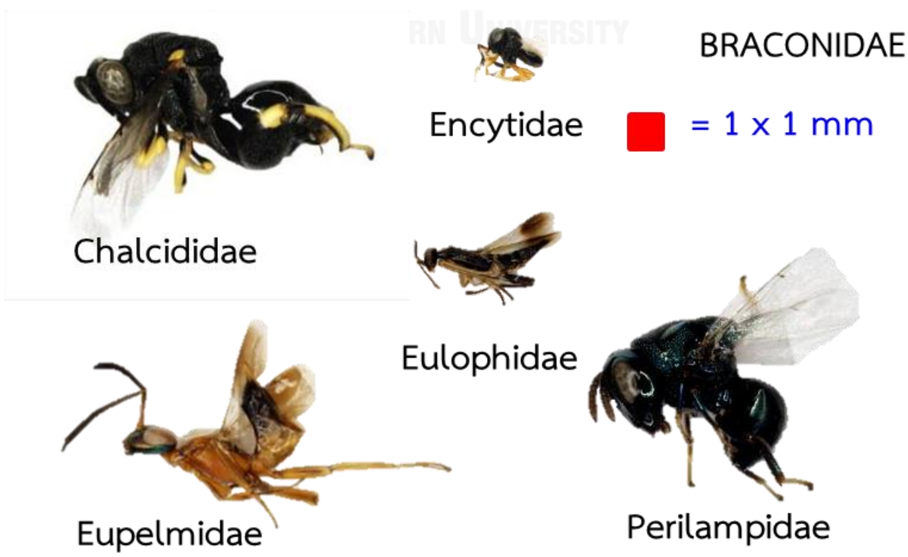
F-1 Parasitic wasps in family Ichneumonidae



F-2 Parasitic wasps in family Braconidae



F-3 Parasitic wasps in superfamily Chalcidoidea



VITA

Mr. Kittipum Chansri was born on August 5, 1988 in Suphanburi Province, Thailand. He graduated a Bachelor's degree in Zoology from Department of Biology, Faculty of Science, Chulalongkorn University in 2011. After his graduation, he continued his MSc. in Zoology at the same institute. Because he is interested in Entomology, therefore he chose to work on parasitic wasps, host-parasitoid interactions and diversity of parasitic wasps at Nan Province for his Master thesis. During his work, he carried out his research in Brassica agricultural areas and The Chulalongkorn University Forest and Research Station, Lainan Subdistrict, Wiang Sa District, Nan Province for more than a year as part of CU-RSPG and CU-ANR-56-01 grants support. During his graduate study, he presented part of his works in both oral and poster presentations at the national and international conferences. He received the gold medal prize for oral presentation in the theme of Biodiversity, Ecology and Environmental Biology, the 18th Biological Sciences Graduate Congress BSGC, 2014, at University of Malaya, Kualar Lumpur, Malaysia. Third place medal for poster presentation in the theme of Biodiversity, Ecology and Environmental Biology, the 19th Biological Sciences Graduate Congress BSGC, 2014, at National University of Singapore, Singapore. He had also published part of his works as a research article in Proceeding of The 9th Conference on Science and Technology for Youths, 2014, in the topic of "Parasitoids of cotton leafworm Spodoptera litura (Fabricius, 1775) in Brassica agricultural areas at Lainan Subdistrict, Wiang Sa District, Nan Province".