THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Doctor of Philosophy (Entomology)

DEGREE

Entomology

FIELD

Entomology

DEPARTMENT

TITLE: Beneficial Predators and their Roles in Controlling Thrips on Lettuce under Hydroponics Cultivation

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THESIS

BENEFICIAL PREDATORS AND THEIR ROLES IN CONTROLLING THRIPS ON LETTUCE UNDER HYDROPONICS CULTIVATION

RATTIGAN SUBMOK

A Thesis Submitted in Partial Fulfillment of
The Requirements for the Degree of
Doctor of Philosophy (Entomology)
Graduate School, Kasetsart University
2014

Rattigan Submok 2014: Beneficial Predators and their Roles in Controlling Thrips on Lettuce under Hydroponics Cultivation. Doctor of Philosophy (Entomology), Major Field: Entomology, Department of Entomology. Thesis Adviser: Assistant Professor Sopon Uraichuen, Dr.Ing. 106 pages.

The effectiveness of three predators in controlling four species of thrips was evaluated on three different cultivars each grown hydroponically in two separate greenhouses at Pathum-Thani and Nakhon Pathom Provinces, Thailand, during January to August 2013. Six cultivars of lettuce Iceberg Lettuce, Red Salad Bowl, Red Rapid, Green Oak, Red Oak and Butter Head were investigated in this research. The thysanopterous insect studied were *Frankliniella schultzei* (Trybom), *Astrothrips globiceps* (Karny), *Chaetanaphothrips orchidii* (Moulton) and *Megalurothrips usitatus* (Bagnall). *F. schultzei* was first detected in February and its population reached the peak in March on Iceberg Lettuce, which was most seriously damaged compared to two other cultivars, Red Salad Bowl and Red Rapid. However, *C. orchidii* populations attained their peaks on Green Oak and Butter Head in May 2013 and on Red Oak in February 2013. Of the three cultivars, Green Oak was most seriously affected. The population dispersion pattern of *F. schultzei* showed a uniform distribution on Green Oak and Red Oak, and a clumped distribution on Butter Head. The effectiveness of three predators, *Mallada basalis* (Walker), *Wollastoniella rotunda* Yasunaga&Miyamoto and *Orius maxidentex* Ghauri as a biological control agents against *F. schultzei* was studied under the laboratory and then the greenhouse conditions.

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ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my respected research advisor, Assistant Professor Dr. Sopon Uraichuen for his invaluable help and constant encouragement throughout the course of this research. I am most grateful for his teaching and advice, not only the research methodologies but also many other methodologies in life. I would not have achieved this far and this thesis would not have been completed without all the support that I have always received from Dr. Sopon Uraichuen.

In addition, I am grateful acknowledge to Associate Professor Kosol Charernsom for his valuable guidance of thrips species during the research work. I am also grateful to Mr. Michael Cooper and Dr. Po-Yung Lai for his valuable suggestions to improve the manuscript in English. My sincere appreciation to the examination chairperson Associate Professor Wiwat Suasa-ard for his valuable suggestions to improve this thesis.

I also wish to express my sincere gratitude to the National Biological Research Center (NBCRC), Central Regional Center Kasetsart University, Kamphang Saen Campus, Nakhon Pathom for providing facilities and to all staff members of NBCRC-CRC for all their help during the my study.

Finally, I most gratefully acknowledge my father, Mr. Anut Submok; my mother, Mrs. Sa-nguan Submok; my grandparent; my brothers, Mr. Athapon Submok and Mr. Aphisit Submok; my boyfriend, Mr. Thanayod Intama and my friends for their love and continuous assistance and encouragement for the successful completion of the study.

Rattigan Submok

July, 2014

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INTRODUCTION

Consumption of organic vegetables has recently increased in Thailand, resulting in a higher popularity of hydroponically grown vegetables among consumers (Thongket, 2007). Hydroponics is a technique, without using soil, for growing plants, including vegetables, in water containing dissolved nutrients (Ernst and Busby, 2009). Using hydroponics for growing vegetables offers the advantage of growing large quantities of vegetables in a relatively smaller area. Lettuce, pakchoi, tomato, sweet pepper and cantaloupe can all be grown using hydroponics (Aracon *et al*., 2005; Thongket, 2007).

In Thailand, Hydroponics is growing rapidly. Current farm vegetables under hydroponics cultivation are more than 150 nationwide which equivalent to planting about 800 cultivation. Each day, fresh vegetable and vegetable products plant under hydroponics cultivation are on sale in Bangkok, about 20,000 kilograms per day and around the country about 80,000-100,000 kilograms per day. This means that these vegetables are popular in Thai consumer. Vegetable production with hydroponics must take into the quality of the vegetables, to a fresh, clean, good taste and safe from toxic residues (Thongket, 2007).

Although growing under hydroponic cultivation has many advantages, it is also a suitable breeding environment for insect pest such as thrips, aphid and whitefly (Driesche *et al*, 2008). The most of natural enemies to control insect pests that level is particularly low under hydroponics cultivation comparing to the general cultivation condition. Therefore the outbreak of the pest under hydroponics cultivation grows quickly and causes serious problems rather than usual planting.

Hence, in order to produce vegetables under hydroponics cultivation still having great quality and safe from toxic residues, this research conducts the using of natural enemies as the main principle to manage insect pests of lettuce grown under hydroponics cultivation.

OBJECTIVES

1. To study population of thrips in lettuce under hydroponics cultivation.

   1.1 Study population of thrips at Muang District, Pathum Thani Province.

   1.2 Study population of thrips at Kamphaeng-Saen District, Nakorn Pathom Province.

2. To study spatial distribution and dispersion patterns of thrips in lettuce.

3. To evaluate predator as biological control agents against thrips under laboratory and hydroponics cultivations.

   3.1 Killing capacity of predators on thrips under laboratory.

   3.2 Predators's effectiveness and role when releasing one species and combination under laboratory.

   3.3 Predators's effectiveness and role when releasing one species and combination under hydroponics cultivation.

LITERATURE REVIEW

HYDROPONICS SYSTEM

Hydroponics is a method of growing plants without soil. Plants may be grown in a nutrient solution only (liquid culture) or they may be supported by an inert medium (aggregate culture). In both systems all of the plants nutritional needs are supplied through the irrigation water (Douglas, 1975).

Hydroponic is a highly exacting and demanding system that requires a greater amount of production knowledge, experience, technical skill and financial investment than many other greenhouse systems. A grower must be committed to meeting the daily demands of production to be successful (Resh, 1992).

The history of hydroponics

Hydroponics basically means working water (hydro means water and ponos means labor). Many different civilizations have utilized hydroponic growing techniques throughout history. The hanging gardens of Babylon, the floating gardens of the Aztecs of Mexico and those of the Chinese are examples of Hydroponic culture. Egyptian hieroglyphic records dating back several hundred years B.C. describe the growing of plants in water. Throughout the last century, scientists and horticulturists experimented with different methods of hydroponics. One of the potential applications of hydroponics that drove research was for growing fresh produce in non-arable areas of the world. It is simple fact that some people cannot grow in the soil in their area. This application of hydroponics was tested during World War II. Troops stationed on non-arable islands in the Pacific were supplied with fresh produce grown in locally established hydroponic systems. Later in the century, hydroponics was integrated into the space program. As NASA considered the practicalities of locating a society on another plant or the Earth’s moon, hydroponics easily fit into their sustainability plans. This research is ongoing. But by the 1970s, it wasn’t just scientists and analysts who were involved in hydroponics. Traditional farmers and eager hobbyists began to be attracted to the virtues of hydroponic growing. A few of the positive aspects of hydroponics include:

- The ability to produce higher yields than traditional, soil-based agriculture

- Allowing food to be grown and consumed in areas of the world that cannot support crops in the soil and

- Eliminating the need for massive pesticide use effectively making our air, water, soil and food cleaner (Douglas, 1975; Resh, 1992).

Advantages and disadvantages of using hydroponics

Advantages

- Crops can be produced on non-arable land (not fit for farming)

- Isolation from diseases or insect pests usually found in the soil

- No weeding or cultivation is needed

Disadvantages

- Requires a large capital input, energy input and labor input

- The grower needs a high degree of competence in plant science, engineering, computer control system and marketing

- The technology is limited to crops of high economic value

- Back-up generator (Resh, 1992; Savage, 1996).

Basic hydroponic system and how they work

There are 6 basic types of hydroponic systems including Wick, Water Culture, Ebb and Flow (Flood and Drain), Drip (recovery or non-recovery), N.F.T. (Nutrient Film Technique) and Aeroponic. There are hundreds of variations on these basic types of systems but all hydroponic methods are a variation or combination of these six (Resh, 1992; Savage, 1996).

Wick System

The wick system is by far the simplest type of hydroponic system. This is a passive system, which means there are no moving parts. The nutrient solution is drawn into the growing medium from the reservoir with a wick. Free plant for a simple wick system are available. This system can use a variety of growing medium. Perlite, Vermiculite, Pro-Mix and Coconut fiber are among the most popular. The biggest drawback of this system is that plants that are large or use large amounts of water may use up the nutrient solution faster than the wick can supply it.

Water Culture

The water culture system is the simplest of all active hydroponic system. The platform that holds the plants is usually made of Styroform and floats directly on the nutrient solution. An air pump supplies air to the air stone that bubbles the nutrient solution and supplies oxygen to the root of the plants. Water culture is the system of choice for growing leaf lettuce, which are fast growing water loving plants, making them an ideal choice for this type of hydroponic system. Very few plants other than lettuce will do well in this type of system.

EBB and Flow (Food and Drain)

The Ebb and flow system works by temporarily flooding the grow tray with nutrient solution and then draining the solution back into the reservoir. This action is normally done with a submerged pump that is connected to a timer. When the timer turns the pump on nutrient solution is pumped into the grow tray. When the timer shuts the pump off the nutrient solution flows back into the reservoir. The timer is set to come on several times a day, depending on the size and type of plants, temperature and humidity and the type of growing medium used.

The Ebb and Flow is a versatile system that can be used with a variety of growing mediums. The entire grow tray can be filled with Grow Rocks, Gravel or Granular Rockwool. Many people like to use individual pots filled with growing medium, this make it easier to move plants around or even move them in or out of the system. The main disadvantage of this type of system is that with some types of growing medium, there is a vulnerability to power outages as well as pump and timer failures. The roots can dry out quickly when the watering cycles are interrupted. This problem can be relieved somewhat by using growing media that retains more water.

Drip System Recovery/Non-Recovery

Drip systems are probably the most widely used type of hydroponic system in the world. Operation is simply, a timer controls a submersed pump. The timer turns the pump on and nutrient solution is dripped onto the base of each plant by a small drip line. In a Recovery Drip System the excess nutrient solution that runs off is collected back in the reservoir for re-use. The Non-Recovery System does not collect the run off.

A recovery system uses nutrient solution a bit more efficiently, as excess solution is reused, this also allows for the use of a more inexpensive timer because a recovery system doesn’t require precise control of the watering cycles.

The non-recovery system needs to have a more precise timer so that watering cycles can be adjusted to insure that the plants get enough nutrient solution and the runoff is kept to a minimum. The non-recovery system requires less maintenance due to the fact that the excess nutrient solution isn’t recycled back into the reservoir, so the nutrient strength and pH of the reservoir will not vary. This means that you can fill the reservoir with pH adjusted nutrient solution and then forget it until you need to mix more. A recovery system can have large shifts in the pH and nutrient strength levels that require periodic checking and adjusting.

N.F.T. (Nutrient Film Technique)

This is the kind of hydroponic system most people think of when they think about hydroponics. N.F.T. systems have a constant flow of nutrient solution so no timer required for the submersible pump. The nutrient solution is pumped into the growing tray and flows over the roots of the plants, and then drains back into the reservoir. There is usually no growing medium used other than air which saves the expense of replacing the growing medium after every crop. Normally the plant is supported in a small plastic basket with the roots dangling into the nutrient solution. N.F.T. systems are very susceptible to power outages and pump failures. The roots dry out very rapidly when the flow of nutrient solution is interrupted.

Aeroponic

The aeroponic system is probably the most high-tech type of hydroponic gardening. Like the N.F.T. systems above the growing medium is primarily air, the roots hang in the air and are misted with nutrient solution. The mistings are usually done every few minutes because the roots are exposed to the air like the N.F.T. systems, the root will dry out rapidly if the misting cycles are interrupted. A timer controls the nutrient pump much like other types of hydroponic systems needs a short cycle timer that runs the pump for a few seconds every couple of minutes.

LETTUCE

Scientific classification

Scientific name: *Lactuca sativa* L.
Common name: Lettuce, Tshilai
Kingdom: Plantae
(unranked): Angiosperms
(unranked): Eudicots
(unranked): Asterids
Order: Asterales
Family: Asteraceae
Genus: *Lactuca*
Species: *sativa*

Binomial name

The family was originally referred to as compositae because the species all seemed to share a compact structure often sprouting in the shape of a head (Rubatzky and Yamaguchi, 1997). The scientific name for common cultivated lettuce is *Lactuca sativa* L. "*Lactuca* means milk forming, *sativa* means common" (Simpson, 1979; Weaver, 1997).

Origin and distribution

Lettuce probably originated from Asia, where it was grown for centuries and its early from were used in Egypt around 4500 BC. The Roman grew types of lettuce resembling the present romaine cultivars as early as the beginning of the Christian era. The crop was used in China by the 7th century A.D. Lettuce is now one of the world's most important salad crops and is grown worldwide. Today, for organic producers lettuce represents one of the most common and highest grossing products for fresh, local markets.(Ryder, 1999; Sanders, 2001; Weaver, 1997; Wolford and Banks, 2009; Zohary, 1991).

The four distinct types of lettuce produced in the U.S. are crisphead or iceberg (Lactuca sativa L., var capitata), butterhead, bib or Boston (L. sativa, var capitata), cos or romaine (L. sativa, var longifolia) and leaf (L. sativar, var crispa). Two another types, stem oe celtuce (L. sativa, var asparagina) and Latin are rarely found outside local or ethnic communities (Lopez *et al*., 1996)

The majority of the lettuce seed produced in the United States comes from the coastal valleys of California. In the Pacific Northwest, lettuce seed has historically been produced in southwestern Idaho, in the Columbia Basin of Washington and in Malheur Couhty in Oregon (Colt *et al*., 1985).

Description of the plant

Lactuca sativa is an annual glabrous herb with a thin tap root and an erect stem 30-100 cm tall, branched in the upper part. Leaves are spirally arranged, forming a dense rosette or a head before bolting. Their shape is oblong to transverse elliptic, orbicular to triangular, undivided to pinnatisect. The leaf margin is entire to setose dentate, often curly. Stem leaves are oblong elliptic, with a cordate base. The inflorescence (capitulum, head) is composed of 7-15 yellow ligules (florets). The heads form a corymbose, densely bracted panicle. Anthocyanin can be distributed on the cotyledons and true leaves, stems and ligules. The involucres are 10-15 mm long, cylindrical; involucral bracts are broadly to narrow lanceolate, light green, with white margins, erect at the stage of fruit maturity. The fruit (achene) has 5 to 7 setose ribs on each side, a beak and a white pappus. Its length (including beak) is 6-8 mm, and its color is white, cream, gray, brown or black. It is a diploid with a basic chromosome number of n=9 (Dostal, 1989; Ryder, 1999; Rubatzky and Yamaguchi, 1997; Dolezalova *et al*., 2002; Grulich, 2004; Kristkova, 2008)

Cultivars

Lettuce is grouped into seven classes, namely butterhead lettuce, crisphead lettuce, cos lettuce, cutting lettuce, stalk (asparagus) lettuce, latin lettuce and oilseed lettuce.

Butterhead lettuce (Var. capitata L. nidus tenerrima Helm) (Kopfsalat, Laitue pomme)

A heading type with soft and tender leaves, eaten raw. It is most popular in England, France, the Netherlands and other western and central European countries (Ryder, 1999). In recent decades many cultivars have been bred and grown in the USA (Ryder, 1999; Mikel, 2007).

Crisphead lettuce or Iceberg Lettuce (Var. capitata L. nidus jaggeri Helm) (Iceberg type, Eissalat, Batavia)

A heading type with thick crisp leaves and flabellate leaf venation, eaten raw. It is mainly cultivated in the USA (Ryder, 1999; Mikel, 2007). However, it is also grown now in western and central European countries, including the Netherlands, the United Kingdom, France, Spain, Belgium, Germany, Poland and the Czech Republic, as well as in Japan, China and Australia (Lebeda *et al*. 2007)

Cos Lettuce (Var. longifolia Lam., var. romana Hort. in Bailey) (Romischer Salat, Laitue romaine)

Plants with tall loose heads, which are sometimes tied up; oblong rigid leaves with a prominent midrib running almost to the apex, are eaten raw or cooked.
The name of the morphotype is taken from the Greek island Cos (Kos), where the type has long been cultivated. Cos lettuce is most common in the Mediterranean countries of Europe, Western Asia and North Africa (Ryder, 1999). According to

Boukema *et al*. (1990), many landraces of this type maintained at the CGN genebank collection originated mainly from Egypt, Iran, Turkey and Syria.

Cutting lettuce (Var. acephala Alef., syn. Var. secalina Alef., syn. Var. crispa L.) (Gathering lettuce, Loose-leaf, Picking lettuce, Schnittsalat)

Non-heading type harvested as whole, open rosettes, occasionally as separate leaves, eaten raw. Cutting lettuces have been very popular in the U.S., Italy, France, the Czech Republic and Slovak Republic (Rodenburg, 1960). This morphotype is extremely heterogeneous. Cultivars may have entire, curled or fringed leaves, from non-lobed to deeply incised margins. The leaves are elongated or broad, having various shades of green, and various patterns and intensities of anthocyanin pigmentation. The Greeks and Romans cultivated cutting lettuces. Boukema *et al*. (1990) stated that CGN genebank landraces of this type came from Turkey and Greece.

Stalk (Asparagus) lettuce (Var. angustana Irish ex Bremer, syn. Var. asparagina Bailey, syn. L. angustana Hort. in Vilm.) (Stem lettuce)

Plants with swollenstalks, which are eaten raw or cooked like asparagus. Leaves can be eaten raw in a very young stage or cooked like spinach (Lebeda and Kristkova, 1995). According to Lindqvist (1960) there are two types recognized within this group. The Chinese cultivars have light grey leaves resembling cos lettuce leaves; the second types have long lanceolate leaves with pointed apices. According to Helm (1954), stalk lettuce originated in Tibet, which would account for its extensive cultivation in China, in the Pamis and India (Rodenburg, 1960). However, the lettuce illustrated in Egyptian tombs is also stalk lettuce and dates back to about 2500 B.C. If lettuce originated in Mesopstamia, it is even older in the Middle East. Both asparagus types and cos like types are found in Egypt. It is possible that Helm (1954) was referring to *L. indica* which is common in the Far east and grown in China, Japan and some Southeast Asian countries (Rubatzky and Yamaguchi, 1997). Stalk lettuce material collected in Afghanistan appeared to be an intermediate between cos and stalk lettuces and is sometimes used as a food for livestock (Boukema *et al*., 1990)

Latin lettuce

Plants have loose heads with thick leathery leaves, dark green color and are eaten raw. It is mainly cultivated in the Mediterranean countries, including North Africa, and in South America (Rodenburg, 1960).

Oilseed lettuce

This type is not eaten as a vegetable. Oilseed lettuce is characterized by a high percentage (35%) of oil in the seeds, which is used for cooking. The oil contains Vitamin E, an essential nutrient (Boukema *et al*., 1990). In Egypt, Cultivation of oil-producing forms has continued to the present time (Ryder, 1999). Boukema *et al*. (1990) mentioned that some of its forms may be either *L. serriola* or *L. sativa* or intermediate types between these two species.

Breeding

L. sativa can easily be bred with closely related species in *Lactuca* such as *L. serriola*, *L. saligna*, and *L. virosa*, and breeding programs for cultivated lettuce have included those species to broaden the available gene pool. Starting in the 1990s, such programs began to include more distantly related species such as *L. tatarica* (Koopman *et al*., 1998)

Nutrition

Lettuce is a low calorie food and is a source of vitamin A and folic acid. Lactucarium (or “Lettuce Opium”) is a mild opiate-like substance that is contained in all types of lettuce. Both the Romans and Egyptians took advantage of this property by eating lettuce at the end of a meal to induce sleep.

PEST OF LETTUCE

Insect pests attacking the leaf of lettuce under hydroponic has been reported on Thrips, aphid, caterpillar and whitefly (Spangler *et al*., 1991; Hoffmann and Frodsham, 1993). More specifically thrips species infestations often give problems to vegetables; e.g., tipburn on lettuces and silver leaf on tomatoes (Jones, 2005; Thompson, 1926), aphid, caterpillar and whitefly less important hydroponic pests. Thrips species include the common blossom thrips, *Frankliniella schultzei* (Trybom) (Milne and Walter, 2007; Adkins *et al*, 2009; Nyasani *et al*., 2009), the western flower thrips, *F. occidentalis* (Pergande), it is found in Green Oak, Red Mignonette, Green Mignonette lettuce in West Australia and Iceberg Lettuce in America (Broughton and Herron, 2007; Liu, 2011; Natwick, 2007), the onion thrips, *Thrips tabaci* Lindeman is found on Iceberg Lettuce in California and South Tasmania (Natwick, 2007; Wilson, 1998), and the melon thrips, *T. palmi* Karny (Thysanoptera: Thripidae) (Arzone *et al*., 1989; Wang and Chu, 1986; Morris and Waterhouse, 2001; Whitfield *et al*., 2005). In addition to, the aphid, *Nasonovia ribis-nigri* (Mosley) is found on Iceberg Lettuce in the North Tasmania, Australia, North America and New Zeeland (AUSVEG, 2004; Cole and Horne, 2006; Palumbo, 2002), Aphid, *Macrosiphum euphorbiae* (Thomas), aphid, *Uroleucon ambrosiae* (Thomas) is found on lettuces in Brazil (De Conti, 2008), aphid, *Myzus persicae* (sulzer) is found on lettuce in Canada (Rekika *et al*., 2009), the bean aphid, *Aphis craccivora* Koch and the turnip aphid, *Lipaphis erysimi* Kalt (Hemiptera: Aphididae). Caterpillar include the beet armyworm, *Spodoptera exigue* (Hubner), the cutworm, *S. mauritia* (Boisdual), the cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae), the imported cabbageworm, *Pieris rapae* (Linnaeus) (Lepidoptera: Pieridae) and whitefly, the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) (Spangler *et al*., 1991; Hoffmann *et al*., 1993).

THRIPS

Thrips belong to the order Thysanoptera, which literally means “fringed wings”. However, the English name for thrips is derived from the Greek word for "woodworm," because early naturalists found various species in dead branches (Mound, 2005). Thysanoptera are characterized by fringed wings in the adult stage, and asymmetric mouthparts (Triplehorn and Johnson, 2005). The left mandible is the only one that develops because the right one is resorbed by the embryo (Heming, 1993). The mouthparts of this order have been described as "punch and suck". The mandible is used to break the external layer of plant cells or pollen grains and the contents are sucked through the maxillary stylets, which are joined to form a tube (Triplehorn and Johnson, 2005).

The order Thysanoptera is divided into two sub-orders, the Tubulifera and Terebrantia. The Tubulifera consists of a single family, the Phlaeothripidae, which consists of over three thousand species, mostly living on fungus in wet tropics (Moritz *et al.*, 2001). Tubulifera use a U-shaped ovipositor, rather than a straight ovipositor like the Terebrantia. The U-shaped ovipositor is used to deposit eggs on the surface of, rather than into the host tissue, as the fungus provides adequate protection for the eggs (Terry, 1997).

In contrast to the predominantly fungivorous Tubulifera, the sub-order Terebrantia includes eight families of thrips that display a wide variety of food preferences and use a saw-like ovipositor to insert one egg at a time into the host tissue (Terry, 1997). The largest and most diverse family of Terebrantia is the Thripidae, which are represented by over 1,750 species in 260 genera. Species of Thripidae range from Greenland to the sub-Antarctic islands (Moritz *et al.*, 2001). One sub-family of Thripidae, the leaf-feeding Pancheatothripinae, comprising 120 species in 35 genera, is found throughout the tropics and sub-tropics, and includes some crop pests. Thripinae, a more diverse sub-family of Thripidae, consists of approximately 1,400 species in over 200 genera. Many feed and 3 oviposit in leaves, and some of the more recently evolved species feed and oviposit in flowers. This group exhibits a wide variety of feeding habits and includes thrips species that are predaceous, anthophagous, phytophagous, or even associated with mosses (Mound, 1997). The wide variety of food preferences of many Thripinae species includes commercial crops, and some of these species can cause direct damage to crops by feeding and oviposition as well by vectoring plant viruses (Mound, 1997; Moritz *et al*., 2001).

Life cycle

Thrips begin their lives as eggs. These are extremely small (about 0.2 mm long) and kidney-shaped. It may take from as little as a day to several weeks before hatching. Thrips then pass through two wingless instars of nymph.

All genera of thrips are haplodiploid organisms capable of parthenogenesis, with some favoring arrhenotoky and others displaying thelytoky (Lewis, 1977)

Thrips as pest species

Of an estimated 8000 extant species of thrips (Lewis, 1997) and more than 5500 species that are described, scarcely 1% was recorded as serious pests. A large part of the economic literature deals with just four species, *T. tabaci* Lindeman, *F. occidentalis*, *Scirtothrips dorsalis* Hood, and *T. palmi* Karny (Morse and Hoddle, 2006; Mound, 2002)

Many species of thrips affect the cosmetic quality of a commodity such that economic returns can be severely impacted. California citrus is grown for the fresh market and is marketed on the basis of visual appeal with minimal or negative grower returns from processed fruit. Despite studies showing that *S. citri* surface scarring has no impact on fruit quality, annual pesticide treatments cost California growers well in excess of $11 million per year (Morse and Hoddle, 2006)

In addition to direct or cosmetic plant damage, thrips vector a number of microbial pathogens through mechanical transmission. In some cases, thrips can have a large impact on international trade. As listed above, thrips are pestiferous in diverse ways and across a broad spectrum of commodities (Mound, 2002).

Population dynamics of thrips

There are two types of plants where thrips have been reported. The first type is a provisional or alternate host, which might offer temporary shelter or food, but in the vast majority of cases thrips do not reproduce in these plants. The second group of hosts might be called proper hosts; these plants offer food, shelter, a reproductive substrate and alimentation for the immature thrips. Unfortunately, there is a controversy about whether the plants reported as hosts in the literature are proper hosts or alternate hosts, and if these alternate hosts should be defined as hosts or if they are just accidental relationships (Mound, 2005). There are approximately 50 economically important pest species among 5,300 known species of thrips. Some thrips species are considered to be very host-specific. Those thrips species that are considered as crop pests are usually very prolific and non-host-specific. For example *F. occidentalis*, the western flower thrips, is reported on more than 500 plant species within 50 families. However, it is necessary to remember there is controversy about reports of host plants (Moritz *et al.*, 2004). Thrips are ideal for population dynamics studies. Their populations are large and are generally easy to sample. However, thrips sampling presents some challenges, such as the difficulty of finding dead thrips and the fact that big migrations go unnoticed most of the time, sometimes for unknown reasons. Some species are very common in one year and very rare in the next. To study their population dynamics, it is necessary to consider feeding and reproductive behavior, migration, short and long term effects of the environment, and the effect of management techniques in the field populations (Kirk, 1997).

Spatial distribution pattern of Thrips sp.

There are several studies among these distribution patterns, the clumped or aggregated distribution has been reported on *F. occidentalis* on greenhouse cucumber.(Cho *et al*., 2001); *Aeolothrips intermedius* Bagnall, *F. intonsa*, *F. occidentalis*, *T. angusticeps* and *T. tabaci* on cotton (Deligeorgidis *et al*., 2002); and *S. dorsalis* on peper (Seal *et al*., 2006).

Measurement of population spatial distribution pattern

The spatial distribution pattern of different species of thrips has been studied by using six methods to determine their population dispersions, which include Taylor's power law (Taylor, 1961), Lloyd's mean crowding (Lloyd, 1967), Iwao's patchiness regression (Iwao and Kuno, 1968), index of dispersion (Patil and Stiteler, 1974), and Morisita's coefficient of dispersion (Pedigo and Buntin, 1994). Furthermore, insect populations are known to follow three distinct distribution patterns; clumped distribution, random distribution and uniform distribution (Southwood, 1978).

Taylor's power law

Taylor (1961) found that a power law function could be used to model the relationship between mean and variance as: $S^2 = am^b$, where S^2 is the variance; *m* the sample mean; *a* is a scaling factor related to sample size and *b* measuring the species aggregation. When $b = 1$, < 1 and > 1, the distribution is random, regular and aggregated, respectively. Through use of a log transformation, one can estimate the coefficients with linear regression as: Log (s^2) = Log (a) +b Log (m), where *a* and *b* are the parameters of the model, estimated by linearizing the equation by a log-log transformation (Taylor, 1961).

Lloyd's Mean Crowding *(X*)*

Mean crowding (X^*) was proposed by Lloyd to indicate the possible effect of mutual interference or competition among individuals. Theoretically mean crowding is the mean number of other individuals per individual in the same quadrate: $x^* = m+s^2/m-1$. As an index, mean crowding is highly dependent upon both the degree of clumping and population density. To remove the effect of changes in density, Lloyd introduced the index of patchiness, expressed as the ratio of mean crowding to the mean. As with the variance-to-mean ratio, the index of patchiness is dependent upon quadrate size x^{*}/m = 1 random, <1 regular and >1 aggregated (Lloyd, 1967).

Iwao's Patchiness Regression

Iwao's patchiness regression method was used to quantify the relationship between mean crowding index (m^*) and mean density (m) using the following equation: $m^* = \alpha + \beta m$, where α indicates the tendency to crowding (positive) or repulsion (negative) and β reflects the distribution of population in space and is interpreted in the same manner as b of Taylor's power law (Iwao and Kuno, 1968). Student t-test can be used to determine whether the colony is composed of single individuals and if colonies are dispersed randomly. Test b = 1: $t = (b-1)/SE_b$ and Test β = 1: $t = (\beta - 1)/SE_\beta$, where SE_b and SE_β are the standard errors of the slope for the mean crowding regression. Calculated values are compared with tabulated t-values with n-2 degrees of freedom. If the calculated t (t_c) < t-table (t_t), the null hypothesis (b = 1) would be accepted and spatial distribution would be random. If $t_c > t_t$, the null hypothesis would be rejected and if b > 1 and b < 1, the spatial distribution would be aggregated and uniform, respectively.

Index of Dispersion

Dispersion of a population can be classified through a calculation of the variance to mean ratio; namely: S^2/m random, < 1 regular and > 1 aggregated. Departure from a random distribution can be tested by calculating the index of dispersion (I_D), where n denotes the number of samples: $I_D = (n-1)\, S^2/m$. I_D is approximately distributed as x^2 with $n-1$ degrees of freedom. Values of I_D which fall outside a confidence interval bounded with n-1 degrees of freedom and selected probability levels of 0.95 and 0.05, for instance, would indicate a significant departure from a random distribution. This index can be tested by Z value as follows: $Z = \sqrt{2I_D} - \sqrt{(2\nu - 1)}$, v = $n-1$. If 1.96 ≥ Z ≥ -1.96, the spatial distribution would be random but if $Z < -1.96$ or $Z > 1.96$, it would be uniform and aggregated, respectively (Patil and Stiteler, 1974).

Morisita's Coefficient of Dispersion *(I_δ)*

Reasoning that the diversity of numbers of individuals per quadrate could be used as a measure of spatial pattern, Morisita (1962) developed the index I_δ. Suppose n quadrates are sampled and x_i represents the number of individuals in the i_{th} quadrate. Define δ as the probability that individuals of a randomly drawn pair will come from the same quadrate. If the x_i came from a random or poisson distribution, the expected value of δ is $1/n$. Then the index I_δ can be defined as the ratio of δ to its expected value assuming a random distribution. Values for I_δ may range from 0 to n and N is the total number of individuals sampled in n quadrate. I_δ is calculated as follows and used to classify population: $I_\delta = n\frac{\Sigma x_i(x_i - 1)}{N(N-1)}$. To determine if the sampled population significantly differs from random, the following large sample test of significance can be used: $Z = (I_\delta - 1)/(2/nm^2)^{(1/2)}$, where m = mean population density per leaf in each sampling date and n = the number of sample units. By comparing the value of Z with tabulated values for a random distribution and reject the hypothesis that the sampled population is dispersed randomly if $|Z| > z(\alpha/2)$ (Pedigo and Buntin, 1994).

Southwood

Using estimating population dispersion ($S^2/\bar{x}$). Which a test statistic was calculated, in this case t, where $t = \frac{S^2/\bar{x} - 1}{S_{\bar{x}}}$, S^2 = variance, $S_{\bar{x}}$ = standard error, $\bar{x}$ = mean. According to this model $S^2/\bar{x} > 1.0$ denotes a population with a clumped distribution, $S^2/\bar{x}$ = denotes a random distribution and $S^2/\bar{x} < 1$ denotes a uniform distribution (Southwood, 1978).

Factors affecting thrips distribution

There are two factors affecting fluctuations of insect populations; density dependent factor or biotic factor and density independent factor or abiotic factor. The latter includes temperature, humidity, rainfall, soil pH and food quality (Pongprasert, 2005). The relationship between an insect species and the abiotic factors can be determined by estimating its population fluctuations (Roy *et al*., 2002). The important effect of meteorological parameters on insect population fluctuations has been reported on plant sucking insects (Gogoi *et al*., 2000; Murugan and Uthamasamy, 2001; Panicker and patel, 2001; Umar *et al*., 2003).

Thrips, *Frankliniella schultzei* (Trybom)

Thrips, *F. schultzei* is a key pest in tomato and cucumber fields in South America (Jones, 2005; Monterio *et al.*, 2001). Thrips, *F. schultzei* has a wide distribution range and it is mainly found in tropical and subtropical areas throughout the world (Vierbergen and Mantel, 1991). It has been reported from Belgium, Spain, Netherlands, United Kingdom in Europe; Bangladesh, India, Indonesia, Iran, Iraq, Israel, Malaysia, Pakistan and Sri Lanka in Asia; Angola, Botswana, Cape Verde, Chad, Congo, Egypt, Ethiopia, Gambia, Ghana, Kenya, Libya, Madagascar, Morocco, Namibia, Niger, Somalia, South Africa, Sudan, Uganda, Zimbabwe in Africa; Central and southern Florida (Funderburk *et al.*, 2007) and Hawaii in USA; Barbados, British Virgin Islands, Cuba, Dominican Republic, Haiti, Jamaica and Puerto Rico in the Caribbean; Argentina (Rio de Janeiro), Brazil (Minas Gerais, Parana, Rio Grande do Norte, Santa Catarina, Sao Paulo), Colombia, Chile, Guyana, Paraguay, Peru, Uruguay, Venezuela in South America; New South Wales, Northern Territory, Queensland, South Australia, Victoria, Western Australia, French Polynesia and Papua New Guinea in Australia and the South Pacific (CABI, 1999).

Thrips, *F. schultzei* has a wide host range and it is known to feed on various ornamental and vegetable hosts in different parts of the world (Palmer, 1990; Vierbergen and Mantel, 1991; Milne *et al.*, 1996). Thrips, *F. schultzei* along with

F. bispinosa (Morgan), *F. occidentalis, and F. tritici* (Fitch) (Cho *et al.*, 2000; Hansen, 2000) are anthophilous species, inhabiting flowers of numerous field crops (Johansen, 2002), and are mainly attracted to the color of the host flowers (Lunau, 2000). The majority of flower thrips feeding on floral parts derive nutrition from pollen. A pollen diet rich in protein and other nutrients increases the fecundity of adult thrips and shortens the development period of larval stages (Tsai *et al.*, 1996). Milne *et al.* (1996) studied the fecundity and development of *F. schultzei* and did not find any significant difference between petal and pollen diets. The major recorded hosts of *F. schultzei* are cotton (*Gossypium sp.*), groundnut (*Apios Americana*), beans (*Phaseolus vulgaris*) and pigeon pea (*Cajanus cajan* (L.)) (Gahukar, 2004). However, due to its polyphagous feeding behavior, it also attacks tomato (*Lycopersicon esculentum*), sweet potato (*Ipomoea batatas*), coffee (*Coffea* sp.), sorghum (*Sorghum* sp.), chillies (*Capsicum annuum*), onion (*Allium cepa*), sunflower (*Helianthus annuus*), rose (*Rosa* sp.), tobacco (*Nicotiana tabacum*), cotton (*Gossypium* sp.), grain legumes (various sp.), lettuce (*Lactuca sativa*), cucumber (*Cucumis sativus*), okra (*Abelmoschus esculentus*), Japanese daisies, irises (*Iris ensata*), spinach (*Spinacia oleracea*), carnation (*Dianthus caryophyllus)*, pumpkin (*Curbita* sp.), *Carola aubergine* and kidney beans (*Phaseolus vulgaris* subsp. *Nunas)*, in different parts of the world (Hill 1975; Monteiro *et al.*, 2001). In Australia, the primary host of this pest is a South American shrub, *Malvaviscus arboreus*, in the absence of which *F. schultzei* infests other non-native plants. The other hosts of this pest, belonging to 12 families includes; *Hibiscus rosasiensis* L. (Malvaceae), *Bauhinia variegate* L. and *B. galpinii* N. E. Brown (Caesalpiniaceae), *Vigna caracalla* L. and *Erythrina crista-galli* L. (Fabaceae), *Ipomoea cairica* (Convolvulaceae*)*, and *Jacaranda mimosifolia* D. Don (Bignoniaceae) (Milne and Walter, 2007; Coutts *et al.*, 2004; Coutts and Jones, 2005). In Thailand, thrips, *F. schultzei* was found in sacred lotus, bean, chrysanthemum, cotton, pepper, onion and cucumber (Poonchaisri and Sengsim, 1993)

Thrips, *F. schultzei* known to originate from South America, is now distributed throughout the world (Mound, 2002). This small insect could have dispersed either artificially or naturally. The artificial mode of dispersal includes the import of various agricultural products including cut flowers, fruits and vegetables infested with this tiny thrips, air passengers, crew and their baggage, air cargo etc. The natural mode includes the dispersal via flying. Another important mode of dispersal is wind; it affects the flight of these tiny thrips, thereby causing the widespread scattering of this group. Mound (2004) reported that *F. schultzei* is highly vagile and thus has the ability to migrate great distances. Vagile behavior, good dispersal capability and the ability to feed on alternative hosts supports rapid dispersal and increase in population of this group including *F. schultzei* in a new habitat. Thus, the incidence of a large number of exotic thrips species in Florida emphasizes the need for correct identification to distinguish them from native thrips in the fauna.

Managenment of Thrips sp.

Biological control

There are three predators of the thrips, they are the green lacewing in order Neuroptera, family Chrysopidae (Hoddle and Robinson, 2004) and two anthocorid bugs in order Hemiptera, family Anthocoridae including *Orius* spp (Lattin, 2000; Gitonga *et al*., 2002; Premachandra and Borgemeister, 2003; Shipp and Wang, 2003), *Wollastoniella rotunda* and *W. parvicuneis* (Hirose *et al*., 1993; Yasunaga and Miyamoto, 1993; Roy and Bellows, 1996). Additionally, the three predators can be used to control aphid, mealy bug, whitefly and red mite (Roy and Bellows, 1996; Lattin, 2000; Hoddle and Robinson, 2004).

Successful thrips control using predators such as *Orius* spp., *O. sauteri* (Poppius), *O. minutus* (Linnaeus), *O. strigicollis* (Poppius), *O. nagaii* Yasunaga and *O. tantillus* (Motschlsky) (Gitonga *et al*., 2002; Driesche *et al*., 2008; Yano, 2004) and *W. rotunda* for controlling *T. palmi* on eggplants and *T. palmi and F. occidentalis* on sweet pepper in greenhouses (Shima and Hirose, 2002; Urano *et al*., 2003; Yano, 2003; Youn *et al*., 2003; Nakashima *et al*., 2004), using *Thripobius semiluteus* Boucek (Hymenoptera: Eulophidae) against *Heliothrips haemorrhoidalis* Bouche (Thysonoptera: Thripidae) in California, Israel and New Zealand (Morse and Hoddle,

2006) and phytposeiid mites e.g. *Neoseiulus cucumeris* (oudemans) (Acari: Phytoseiidae) against *F. occidentalis* in cucumber (Shipp and Wang, 2003) had been shown. In addition to using predators, cultural control strategies can also be jointly employed for example vermicomposts, sticky trap and enzyme lonic plasma (Aracon *et al*., 2005; Yadim *et al*., 2006).

Fungal pathogen, in particular, *Beauveria bassiana* (Balsamo), *Metarhizium anisopliae* (Metchnikoff), *Paecilomyces fumosoroseus* and *Verticillium lecanii* have been evaluated for use against various thrips in greenhouse either alone or in combination with other natural enemies or insect attractants (Ludwig and Oetting, 2002). Jacobson *et al*. (2001) reported that sprays of *B. bassiana* can significantly reduce *F. occidentalis* population on cucumber and are compatible with augmentative release of phytoseiid mites.

Cutural Control

Hoddle *et al*., 2002 reported that the use of composted organic yard waste has been investigated as a strategy for disrupting population of *S. perseae* Nakahara larvae by promoting an antagonistic microarthropod, nematode and fungal fauna under avocado trees. Ground covers have been manipulated to promote populations of phytoseiid predators in citrus orchards for control of *S. citri* (Moulton) and wind-break pollen has been used to increase resident population of *Euseius addoensis addoensis* (Van der Merwe and Ryke) (Acari: Phytoseidae) for control of *S. aurantii* Faure in South African citrus orchards (Morse and Hoddle, 2006). Spays of jasmonic acid a natural plant defense elicitor reduced for *F. occidentalis* feeding on cotton, but this technology requires further testing prior to commercial implementation (Omer *et al*., 2001)

Utilization of multiple cultural techniques such as cover crop, modification of tillage practices and removal of alternative weed host plants also been largely ineffective in managing pest thrips (Hummel *et al*., 2002)

Crop Breeding

Morse and Hoddle, 2006 reported that improvements in crop breeding and other molecular technologies will likely form the cornerstone of future management for the many serious Tospovirus disease that are vectored by thrips (Whitfield *et al*., 2005). To date, vector control has been ineffective and only with the integrated use of moderately resistant cultivars, chemical control and cultural practices have wilt epidermics been managed effectively. Substantial research has focused on vegetable crop plant varieties tolerant or resistant to thrips (Frei *et al*., 2004)

Chemical control

Eradication using insecticide treatments, methyl bromide soil sterilization and imidacloprid treated. It is unclear to what degree revenue from exports liable to carry *T. palmi* might have been lost but the benefit-to-cost ratio for this eradication was estimated to be between 4:1 and 9:1 if there was no loss of exports and between 95: 1 and 110: 1 if significant export losses had resulted from *T. palmi* establishment and spread (Macleod. *et.al*., 2004)

MATERIALS AND METHODS

1. Population fluctuation of thrips in lettuce under hydroponic cultivation

Study site

This study was carried out in two separate greenhouses covered with fine mesh nets (32 mesh per in^2) in Thailand; one in Muang District, Pathum-Thani Province and the other in Kamphaeng Saen District, Nakhon-Pathom Province. In each of the test sites, a hydroponic system was installed to sustain the growth of the test plants.

Designs of the hydroponic systems

System A - The hydroponic system installed in Muang District was constructed with 6 A-frames (6.25 x 0.85 x 1.33 m) made of metal pipes of 0.10 m in diameter. The 6 metal A-frames were welded onto a long metal pipe of 6.25 m in diameter to provide support for the A-frames. Six pre-fabricated hydroponics troughs (6.25 x 0.05 0.10 m), made of plastic with covers, were affixed to each side of the 6 A-frames and evenly spaced to ensure maximum light available for each test plant grown in the trough. There were a total of 12 hydroponic troughs on both sides of the A-frames (Figure 1 and 2). On each of the trough covers in System A, 24 holes, 5 cm. in diameter, were drilled to provide openings for transplanting of test plant seedlings and also for providing physical support for the growth of the test plants.

System B – The hydroponic system installed in Kamphaeng Saen District had a different design from that of System A. System B was consisted of 5 basket-like, pre-fabricated units. Each unit was composed of 5 plastic hydroponic troughs (2.0 x 0.80 x 0.85 m), which were arranged in evenly spacing from the top to the bottom of each unit to allow each test plant to receive maximum light for its growth. Each of the 5 units was fixed to 3 square posts of 6.8 cm^2 for support. On each of the plastic trough cover in System B, 10 holes of 5 cm in diameter were drilled to provide openings for transplanting of test plant seedlings and also for providing physical support for the growth of the test plants (Figure 3).

In System A, three cultivars of lettuce; Iceberg Lettuce (Figure 4A), Red Salad Bowl (Figure 4B) and Red Rapid (Figure 4C), were used as the test plants. There were 8 test plants per each cultivar grown in each of the 6 troughs. As a result, there were 24 test plants grown in each of the 6 troughs, resulting in a total of 144 plants grown on one side of the A-frame. Likewise, there were a total of 144 plants on the other side of the A-frame. The combined total of 288 plants was used in the study under System A.

In System B, three different cultivars of lettuce; Green Oak (Figure 5A), Red Oak (Figure 5B) and Butter Head (Figure 5C), were used as the test plants. There were 3 test plants per each cultivar grown in each of the 5 troughs in a unit. As a result, there were 15 plants per cultivar grown in each unit with a total of 75 plants per cultivar grown in 5 units. A similar number of 75 plants were also grown for each of the two other cultivars.

The test plants used in System A and B were grown according to the Nutrient Film Technique (NFT), in which, a sponge was placed at the bottom of a nursery tray (60 x 40 cm) and soaked with water. A lettuce seed was embedded at a depth of 1.2 cm in a pre-cut hole on each sponge. After all the lettuce seeds were properly planted, the tray was submerged in water half way from the top of the tray to ensure the seed was kept in moist condition. The tray was kept in a dark condition and was watered twice a day in the morning and evening. The seed began to germinate in the sponge in 2-3 d. after seeding. The tray was moved from shade to sunlight condition to enable the one-day old sprouts to receive 5-6 hr. of sunlight per day in the greenhouse. This was repeated for 4-5 d. until the sprouts reached 7 d. old when the true leaves and roots emerged. An aliquot of 5 ml of the nutrient solution was poured on the sponge to provide nutrients to the seedlings.

Preparation of nutrient solution

The nutrient solution was prepared by mixing 1L of water with 5 cc of Nutrient A (Calcium Nitrate and Fe-EDTA) and after the solution was thoroughly mixed, then added 5 ml of Nutrient B (Mono potassium phosphate + Potassium Nitrate + Magnesium sulphate + Manganese + Micro Elements). About 200 ml of the nutrient solution was poured on the sponge to keep it in wet condition to allow the continued growth of the seedlings. When the seedling grew to 14 d old, they were transplanted to a stylophone cup (5 cm in diameter and 10 cm in depth), which was inserted into the trough through the opening on the cover as described above. The trough was filled with the nutrient solution circulated by a motor pump (Fa Fresh Farm Co. Ltd, 2012), which was turned on at 08.00-09.00 am and 04.00-05.00 pm.

Figure 1 An aluminum A-frame used to hold the plastic hydroponic trough for growing lettuce in Muang District, Pathum-Thani Province

Figure 2 The 6 plastic hydroponic troughs attached to one side of the aluminum A-frames for growing lettuce in Muang District, Pathum-Thani Province. Each trough contains 24 plants

Figure 3 Aluminum units (each measured 2.0x0.85×0.80 m.) used for growing lettuce in Kamphaeng Saen District, Nakhon-Pathom Province. Each unit consisted of 5 troughs and each trough contained 10 lettuce plants of one cultivar, resulting in a total of 50 plants of one cultivar grown in one unit

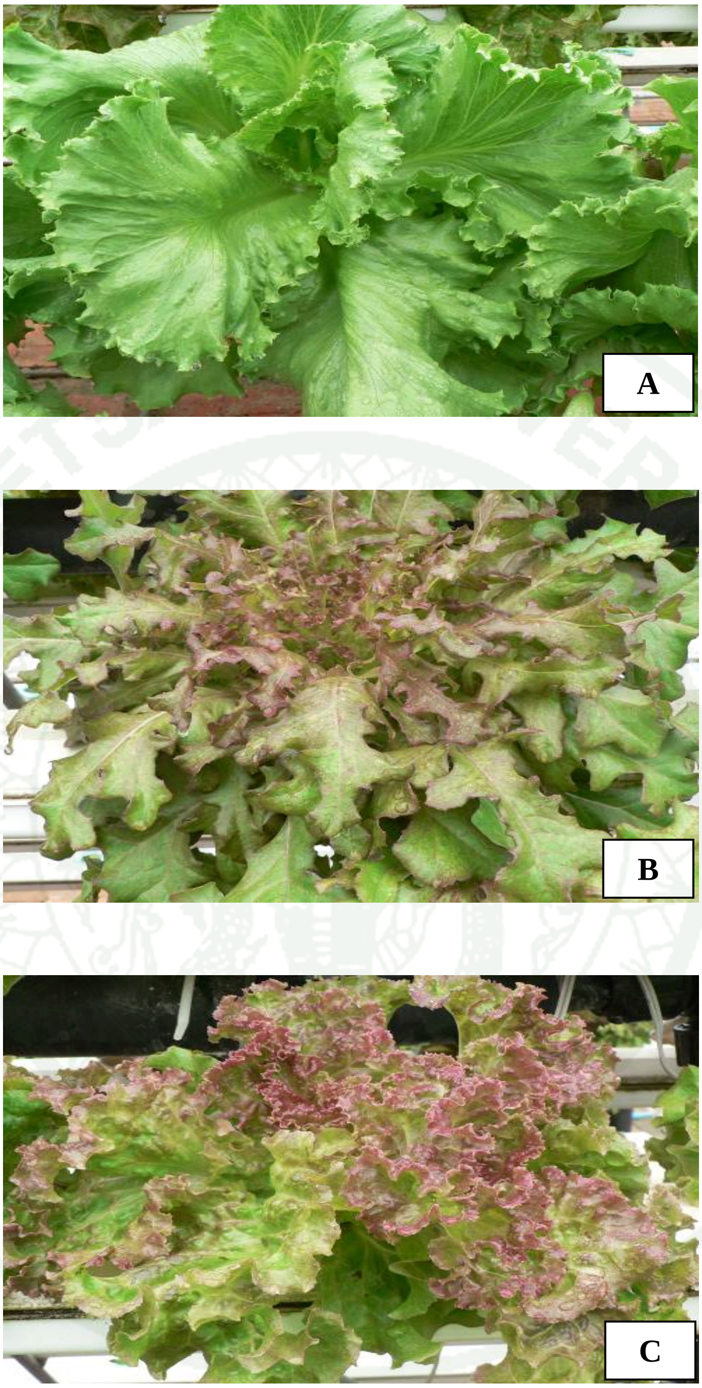


Figure 4 Three cultivars of lettuce, Iceberg Lettuce (A), Red Salad Bowl (B) and Red Rapid (C) were studied in Muang District, Pathum-Thani Province

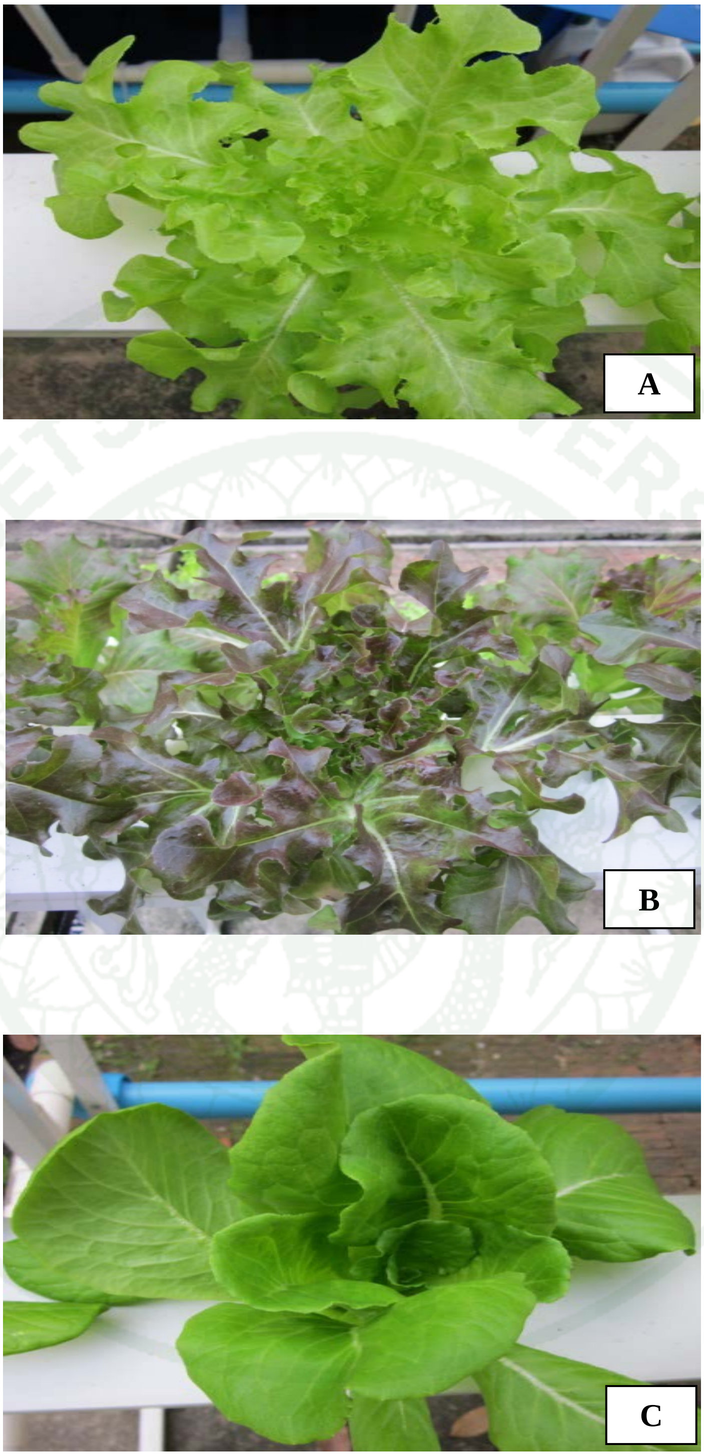


Figure 5 Three cultivars of lettuce, Green Oak (A), Red Oak (B) and Butter Head (C) were studied in Kamphaeng Saen District, Nakhon-Pathom Province

1.1 Population fluctuation of thrips in Muang District, Pathum - Thani Province

This study was conducted in Muang District, Pathum-Thani Province between January to August 2012, using the System A procedures as described above. The three lettuce cultivars used in this study were Iceberg Lettuce, Red Salad Bowl and Red Rapid. A sample of one leaf per plant with a total 100 leaves per cultivar was randomly sampled at 7-day intervals until the lettuce was harvested. The first leaf sample was taken one day after transplanting when the lettuce was 16 days old. The number of thrips present on the leaves sampled was counted and recorded. The relative abundance of thrips per leaf from each of the three cultivars was determined. Also recorded were the temperature, humidity and the conditions of the lettuce leaves sampled.

1.2 Population fluctuation of thrips in Kamphaeng Saen District, Nakhon - Pathom Province

This study was conducted in Kamphaeng Saen District, Nakhon-Pathom Province between July 2012 to June 2013, using the System B procedures as described above. The three lettuce cultivars used in this study were Green Oak, Red Oak and Butter Head. A sample of one leaf per plant with a total 50 leaves per cultivar was randomly sampled at 7-day intervals until the lettuce was harvested. The first leaf sample was taken one day after transplanting when the lettuce was 16 days old. The number of thrips present on the leaves sampled was counted and recorded. The relative abundance of thrips per leaf from each of the three cultivars was determined. Also recorded were the temperature, humidity and the conditions of the lettuce leaves sampled.

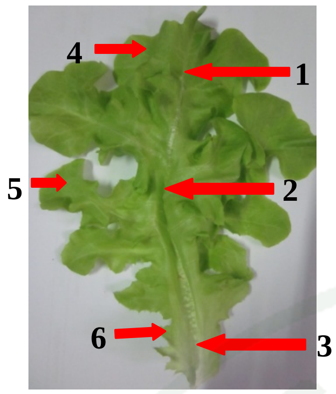
Data Analysis

Data were first transformed by taking Log N+1 and then subject to Tukey's Range Test to determine whether there was a significant difference in the relative abundance of thrips on the three cultivars of lettuce in the greenhouse conditions. The data were also subject to the regression analysis to determine their relationship with such abiotic factors as temperature and humidity recorded in the greenhouse.

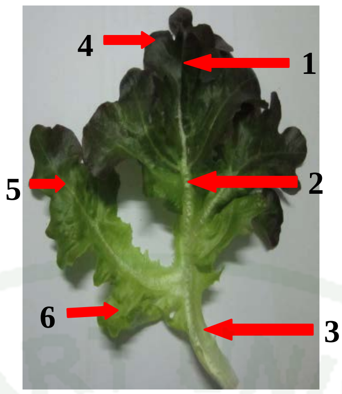
2. Spatial distribution and dispersion patterns of thrips in lettuce

This study was conducted in Kamphaeng Saen District, Nakhon-Pathom Province during January to March 2013 using the System B procedures as described above. The three lettuce cultivars used in this study were Green Oak, Red Oak and Butter Head. A sample of one leaf per plant with a total of 50 leaves per cultivar was sampled at 7-day intervals until the lettuce was harvest. The spatial distribution patterns of *F. shultzei* on the three lettuce cultivar were determined by counting the number of thrips present at each of the 6 pre-selected sampling points on the upper side of a lettuce leaf of each cultivar including 1 - the mid rib of the apex of leaf; 2 - the mid rib of the middle of leaf; 3 - the mid rib of the base of leaf; 4 - the margin of the apex of leaf; 5- the margin of the middle leaf; and 6 - the margin of the base of leaf (Fig. 6A-C). The same sampling procedures were repeated on the underside of a lettuce leaf of each cultivar (Fig. 6D-F).

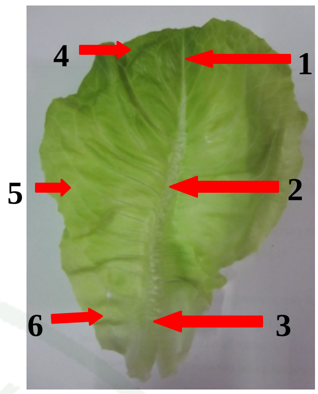
The dispersion patterns of *F. shultzei* on the leaf of three lettuce cultivar were determined by counting the number of thrips present on the 7 leaves in a lettuce head as shown on Green Oak (Fig. 7A) and Butter Head (Fig. 7B).



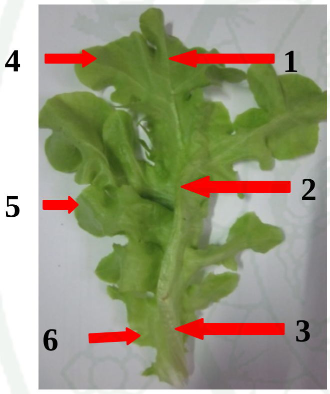
A. The upper side of Green Oak



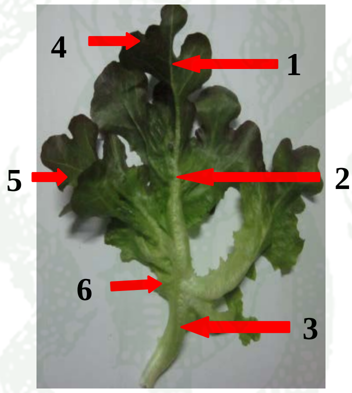
B. The upper side of Red Oak



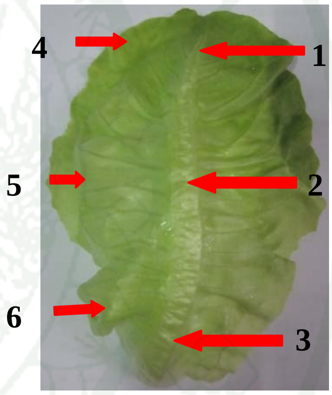
C. The upper side of Butter Head



D. The underside of Green Oak

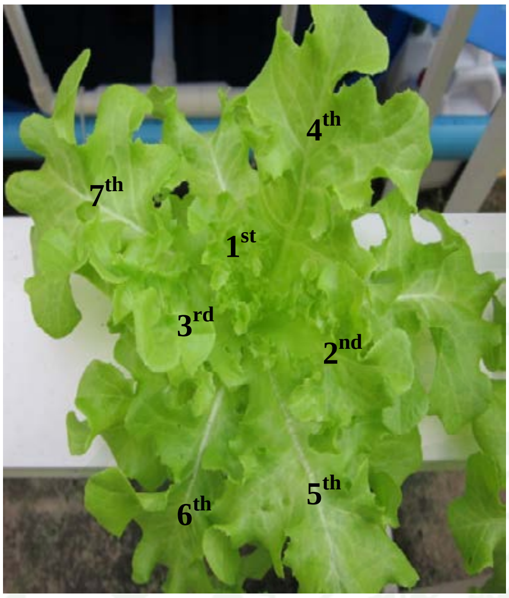


E. The underside of Red Oak

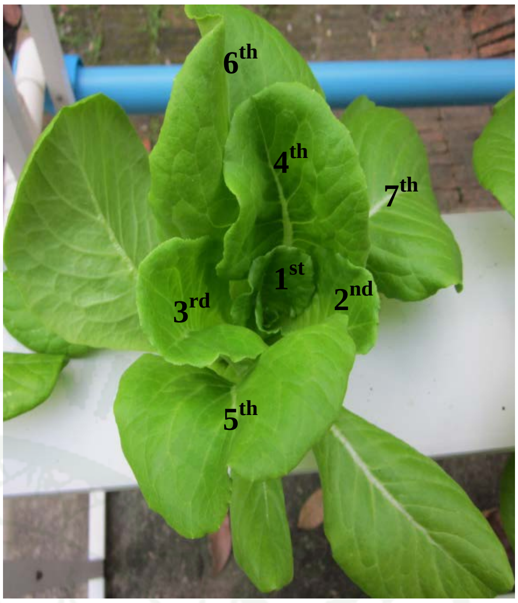


F. The underside of Butter Head

Figure 6 Spatial distribution pattern of thrips in each position on leaf of three cultivars of lettuce



A. The number leaf of Green Oak



B. The number leaf of Butter Head

Figure 7 Dispersion patterns of *F. shultzei* in each of a leaf of the three cultivars of lettuce

Data Analysis

The spatial distribution patterns of *F. shultzei* on the upper- and under-side of a lettuce leaf were determined by using t = $\frac{S^2/\bar{x}-1}{S_{\bar{x}}}$ (Southwood, 1978). The dispersion patterns of *F. shultzei* on a leaf of three lettuce cultivar were analyzed by Turkey's Range Test.

3. Predators's effectiveness and role when releasing one species and combination under laboratory and hydroponics cultivations

Study Sites

The study was carried out under both laboratory and hydroponics cultivation conditions; samples were incubated in an environmental chamber at 37±2 ^{O}C and 55±2 % RH at the National Biological Control Research Center, Kasetsart University Kamphaeng Sean Campus, Nakhon Pathom Province, Thailand.

Rearing of predators and thrips

All of the three predators, the green lacewing, *M. basalis* and two anthocorid bugs, *W. rotunda* and *O. maxidentex* (Figure 8) and the thrips, *F. schultzei* were reared at the National Biological Control Research Center. The thrips were reared on lettuce grown under hydroponics cultivation.

Rearing of *M. basalis*

300 newly eggs were placed in the cylindrical plastic boxes, 23 cm diameter by 11 cm height, with tightly fitting lids having 10 cm diameters circular wire-mesh screen for ventilation. During the 1st, 6th and 8th day, new emerged larvae were fed by the UV sterilized rice moth, *Corcyra cephalonica* Stainton. Adults were placed in the cylindrical poly vinyl chloride tube (PVC tube), measuring of 30 cm diameter by 40 cm height and were fed by honey mixed with yeast (1:1), water supplied on cotton pads that were hung on the top of the tube. The 4th day, eggs laid inside the PVC tube were harvested using Sodium hypochlorite and water. Then, eggs were aerated until dry (Uraichuen *et al*., 2008)

Rearing of *W. rotunda*

Nymphs were reared on eggplant plant which it had red mite on the leaf. Adults were reared on the leaf of two months of eggplant plant and were fed by the egg of *C. cephalonica* . The leaf of eggplant plant was covered with a net cotton bag (Uraichuen *et al*., 2011).

Rearing of *O. maxidentex*

Nymphs were reared in a plastic box size 15×21×7.5 cm and were fed by the egg of *C. cephalonica*. Both of adults, male and female were reared on the leaf of two months of eggplant plant. The leaf of eggplant plant was covered with a net cotton bag (Kernasa *et al*., 2011).

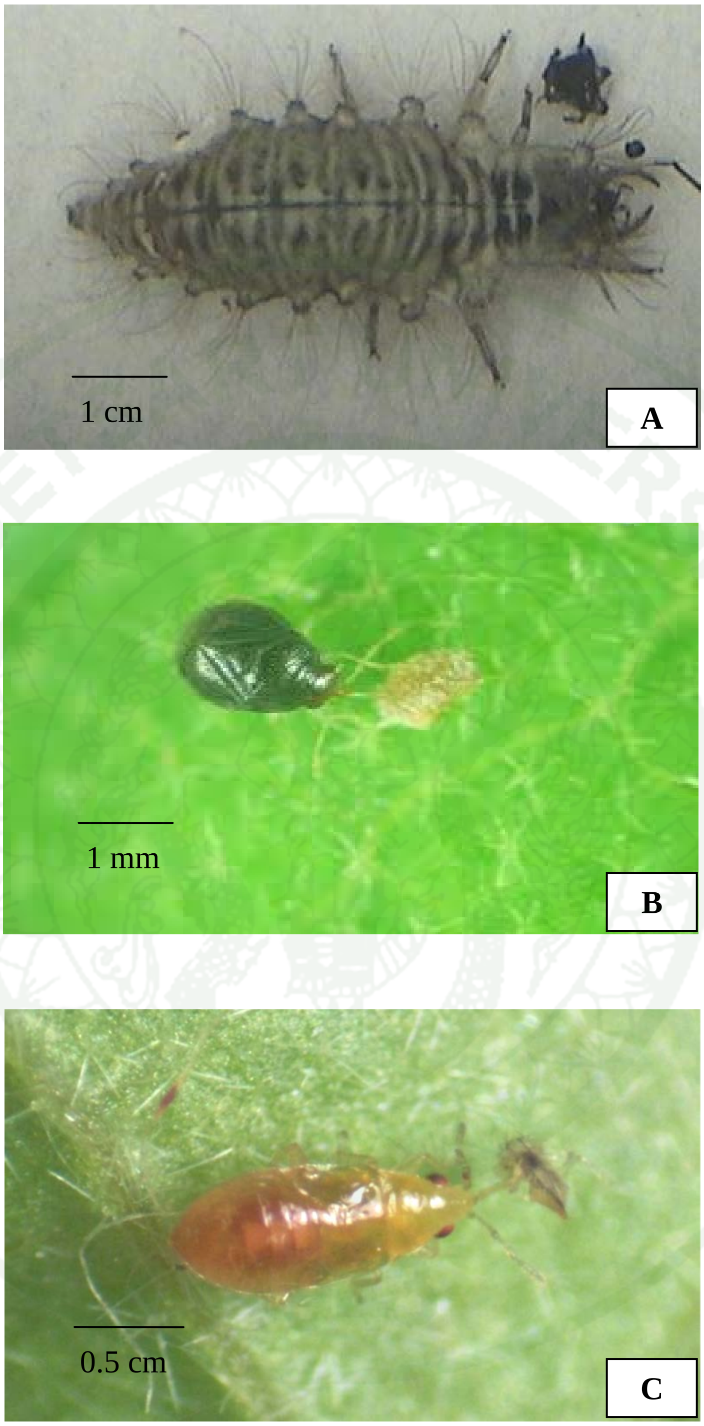


Figure 8 Three predators for studying**,** the green lacewing, *M. basalis* (A) the anthocorid bugs, *W. rotunda* (B) and *O. maxidentex* (C)

3.1 Killing capacity of predators on thrips under laboratory condition

In the killing capacity study of the three predators *M. basalis* , *W. rotunda* and *O. maxidentex*. The experiment was designed in a Completely Randomized Design (CRD), with 15 treatments and 10 replications including 1) the first instar of *M. basalis* 2) the second instar of *M. basalis* 3) the third instar of *M. basalis* 4) the first instar of *W. rotunda* 5) the second instar of *W. rotunda* 6) the third instar of *W. rotunda* 7) the forth instar of *W. rotunda* 8) the fifth instar of *W. rotunda* 9) the adult instar of *W. rotunda* 10) the first instar of *O. maxidentex* 11) the second instar of *O. maxidentex* 12) the third instar of *O. maxidentex* 13) the forth instar of *O. maxidentex* 14) the fifth instar of *O. maxidentex* 15) the adult instar of *O. maxidentex*.

Both nymph and adult thrips, *F. schultzei* were randomly selected from lettuce grown under hydroponics cultivation. One hundred thrips were then placed on a lettuce inside a spherical plastic container, 8 cm diameter by 5 cm height, which was sealed with a lid, having a 3 cm diameter fine circular cotton screen for ventilating. Each treatment was placed individually into the plastic container. The container was next placed into a control cabinet, which was inside an environment chamber programmed to control the environment at $37 \pm 2\ ^{O}C$ and 55 ± 2 % RH. The duration time of each treatment was 24 hours.

3.2 Predators's effectiveness and role when releasing one species and combination under laboratory condition

The experiment was designed in Completely Randomized Design (CRD). The three predators used were, 1) the second instar of *M. basalis* 2) the third instar of *W. rotunda* and 3) the third instar of *O. maxidentex*. There were 5 groups, each with 14 treatments and 3 replications of releasing, The first group; without interspecific competition-one species was released, including 1) releasing *M. basalis* 2) releasing *W. rotunda* 3) releasing *O. maxidentex*. The second group; consisted of two predators released at the different times during a 24 hours period, including 4) releasing

M. basalis and *W. rotunda* 5) releasing *M. basalis* and *O. maxidentex* 6) releasing *W. rotunda* and *M. basalis* 7) releasing *W. rotunda* and *O. maxidentex* 8) releasing *O. maxidentex* and *M. basalis* 9) releasing *O. maxidentex* and *W. rotunda*. The third group; consisted of two predators released at the same time, including 10) releasing *M. basalis* and *W. rotunda* 11) releasing *M. basalis* and *O. maxidentex* 12) releasing *W. rotunda* and *O. maxidentex*. The fourth group; three predators released together, including 13) releasing *M. basalis, W. rotunda* and *O. maxidentex*. The fifth group; 14) an untreated control in which no predator were released (Control treatment)

Both nymph and adult thrips, *F. schultzei* were randomly selected from one cultivar of lettuce, Green Oak grown under hydroponics cultivation. One hundred thrips were then placed on a lettuce inside a spherical plastic container, 8 cm diameter by 5 cm height, which was then sealed with a lid, 3 cm in diameter, of fine cotton cloth for ventilating. Each treatment was released into the plastic container. The container was next placed into a control cabinet which was inside an environment chamber programmed to control the environment at 37±2 ^{O}C and 55±2 % RH. The duration time of each treatment was 48 hours.

3.3 Predators's effectiveness and role when releasing one species and combination under hydroponics cultivation

The study was carried out on Green Oak cultivar of lettuce using the System B procedures as described above. The experiment was designed in Completely Randomized Design (CRD). There are 5 treatments with 3 replications for releasing predators, 1 lettuce per replication. The five treatments evaluated were 1) one species was released, *M. basalis*, 2) releasing *M. basalis* and *W. rotunda* at the different times during a 24 hours period, 3) releasing *M. basalis* and *W. rotunda* at the same time, 4) releasing *M. basalis, W. rotunda* and *O. maxidentex* together and 5) an untreated control in which no predator were released (Control treatment). Releasing at 7-day intervals until the lettuce was harvested. The first releasing was taken one day after transplanting when the lettuce was 16 days old, totally 6 times.

Statistical analysis

Under laboratory, the data recorded was the number of thrips, *F. schultzei* that remained to determine the best thrips population control treatment and then statistically analyzed using Tukey's Range Test. Hydroponics cultivation, the number of thrips, *F. schultzei* before and after releasing predator in each treatment were recorded and then control efficiency percentage analyzed are as follows (Püntener, 1981)

Control efficiency perentage (%) = [1- (Ta/Ca×Cb/Tb)] 100

Where is,

Tb is the mean number of thrips on the treated group before treatment

Ta is the mean number of thrips on the treated group after treatment

Cb is the mean number of thrips on the untreated control group before treatment

Ca is the mean number of thrips on the untreated control group after treatment

4. Places

All studied were conducted in the laboratory and hydroponics cultivation of National Biological Control Research Center-Central Regional Center, Kasetsart University Kamphaeng-Saen Campus, Nakorn Pathom Province and hydroponics cultivation of Muang District, Pathum-Thani Province.

5. Duration Time

Duration of the study during June 2011 to August 2013.

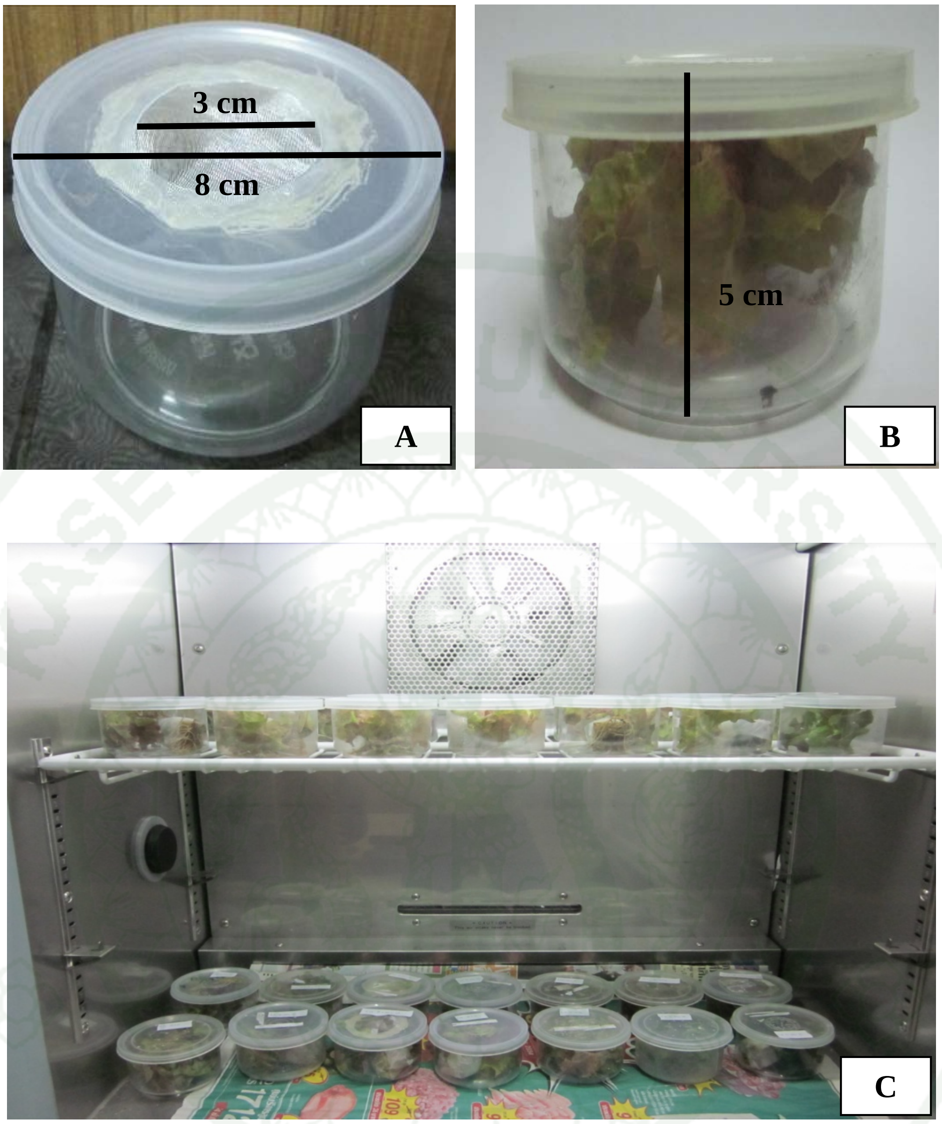


Figure 9 Equipment for studying predators's effectiveness and role to control thrips under laboratory, a spherical plastic container, 8 cm diameter by 5 cm height, which was sealed with a lid, having a 3 cm diameter fine circular cotton screen for ventilating (A and B) and an environment chamber programmed to control the environment at 37$\pm$2 ^{O}C and 55$\pm$2 % RH (C)

Figure 10 Covering the lettuce, Green Oak, by using nylon net for studying predators's effectiveness and role when releasing one species and combination under hydroponics cultivation

RESULTS AND DISCUSSIONS

Results

1. Population fluctuation of thrips in lettuce under hydroponic cultivation

1.1 Population fluctuation of thrips in Muang District, Pathum-Thani Province

In System A, lettuces, including Iceberg, Red Salad Bowl and Red Rapid, were sampled between January to August 2012. Only one thysanopterous insect species was eventually collected from the lettuce samples, this was *F. schultzei* (Figure 11). Populations of *F. schultzei* in three cultivars were first detected on the lettuce leaves sampled in January. The populations reached their peak in March and then, gradually declined in April. In June to August, Populations of *F. schultzei* on Iceberg Lettuce gradually declined from June to July and then increased in August. Populations of *F. schultzei* on Red Salad Bowl steadily increased from June to August. While in Red Rapid populations of *F. schultzei* reached their peak in July and decrease in August at 32 ^{O}C to 47^{O}C, RH 33% to 76% (Figure 12).

Considering the damage caused by the thrips on the three cultivars of lettuce, no damage was observed in January and April as the mean number of the thrips was 0. The mean numbers of the thrips on the three cultivars were significantly different in February (F = 49.94), March (F = 10.26), June (F = 481.46), July (F = 9.18) and August (F = 122.51) at $P < 0.01$. Among the three cultivars, the damage caused by the thrips showed that Iceberg lettuce was the most serious, followed by Salad Bowl and Red Rapid, which was the least serious.

Figure 12 showed that except in April when there was no thrips detected, the mean numbers of the thrips per leaf on Iceberg Lettuce were significantly higher in the dry season months in February and March than that in the wet season months in June, July and August at $P<0.01$. However, a similar result was not observed on the other two cultivars, Red Salad Bowl and Red Rapid (Figure 12). Figure 12 also showed that the mean numbers of the thrips per leaf on Iceberg Lettuce, Red Salad Bowl, and Red Rapid were at their highest in March at 151.7, 90.0 and 76.3 thrips, respectively (Appendix Table 1).

The mean temperature and the mean relative humidity recorded during the study were at 37.08 ^{O}C and 55% RH, respectively (Appendix Figure 1).

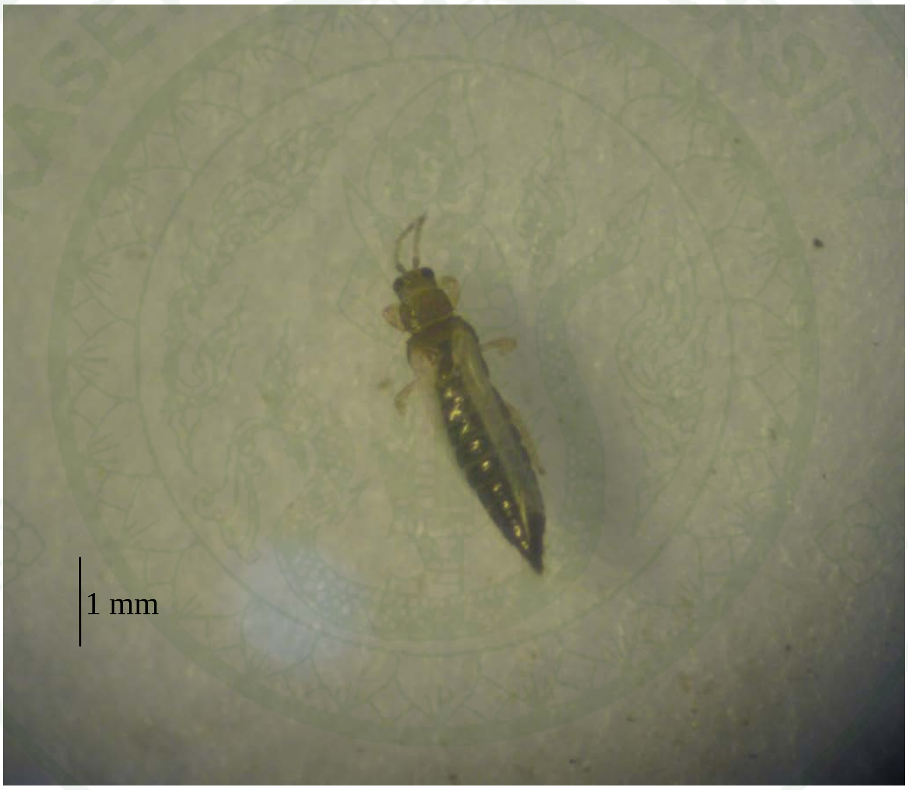


Figure 11 The common blossom thrips, *Frankliniella schultzei* (Trybom) (Thrysanoptera: Thripidae).

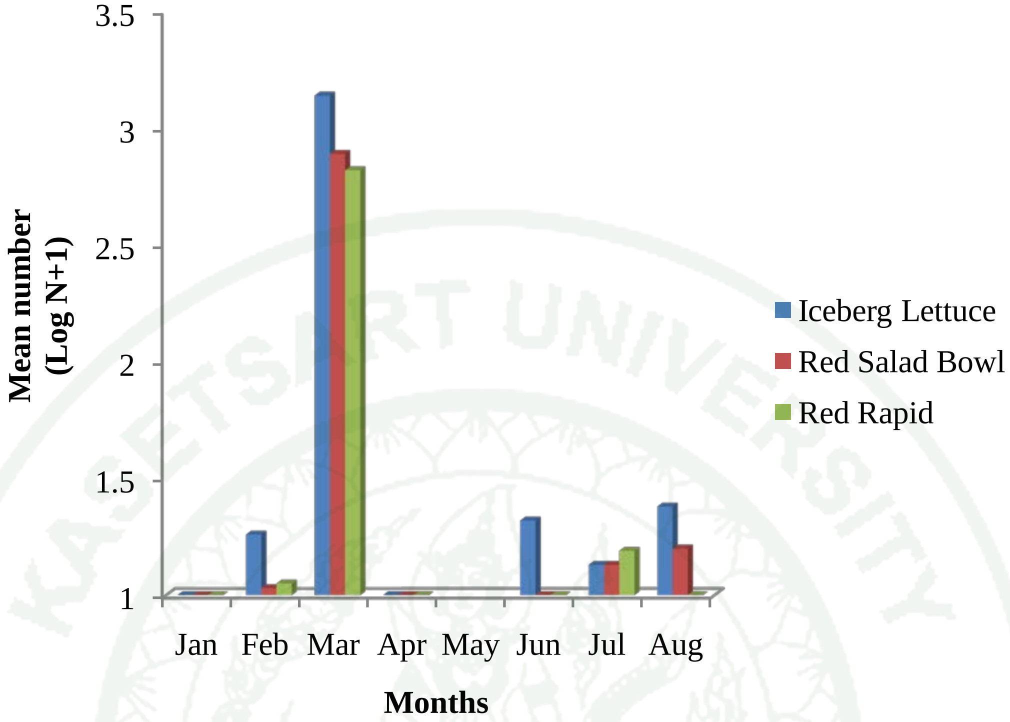


Figure 12 Mean number of *Frankliniella schultzei* (Trybom) per leaf caught in three lettuce cultivars of Iceberg, Red Salad Bowl and Read Rapid, grown hydroponically in a greenhouse

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The variable factors considered that may have affected the thrips, *F. schultzei* population dynamic in the three cultivar of lettuce were temperature and humidity.

The correlation coefficient analysis between the mean temperature and the thrips populations on Iceberg lettuce, Red Salad Bowl and Red Rapid showed that there was no significant correlation $P<0.05$ with R^2 at 0.039, 0.037 and 0.042, respectively (Appendix Figure 3). Similarly, no significant correlations were observed between the humidity and the thrips populations on Iceberg Lettuce, Red Salad Bowl and Red Rapid at $P<0.05$ with R^2 at 0.043, 0.043 and 0.046, respectively(Appendix Figure 4).

1.2 Population fluctuation of thrips in Kamphaeng Saen District, Nakhon-Pathom Province

In System B, lettuces, including Green Oak, Red Rapid and Butter Head were sampled between July 2012 to June 2013. Three thysanopterous insect species were eventually collected from the lettuce samples, there were, *Astrothrips globiceps* (Karny) (Figure 13A), the anthurium thrips *Chaetanaphothrips orchidii* (Moulton) (Figure 13B) and the bean blossom thrips, *Megalurothrips usitatus* (Bagnall) (Thrysanoptera: Thripidae) (Figure 13C) (Thrysanoptera: Thripidae). *C. orchidii* were the most found in three cultivars of lettuce more than two species. *C. orchidii* population in Green Oak and Butter Head attained to peak in May 2013, the mean number of thrips was 12.00 and 4.94 respectively. In Red Oak attained to peak in February 2013, the mean number of thrips was 0.56. In December 2012 to January 2013, thrips populations in three cultivars of lettuce were not found at 31.9 ^{O}C to 35.9 ^{O}C, RH 44% to 68% (Figure 14).

Considering the damage caused by the thrips on the three cultivars of lettuces no damage was found in October, December 2012 and January 2013 as the mean number of the thrips was 0. The mean number of the thrips on the three cultivars were significantly different in July (F = 8.06), August (F = 16.06), September (F = 18.0), November 2012 (F = 9.85), February (F = 3.34), March (F = 7.63), April (F = 38.31), May (F = 68.89) and June 2013 (F = 9.60), at $P < 0.01$. Among the three cultivars, the damage caused by the thrips showed that Green Oak was the most seriious, followed by Butter Head and Red Oak, which was the least serious.

Figure 14 showed that except in October, December 2012 and January 2013 when there was no thrips detected, the mean numbers of the thrips per leaf on Green Oak were significantly higher in the dry season months in February to May than that in the wet season months in June to September at $P<0.01$. However, a similar result was not observed on the other two cultivars, Red Oak and Butter Head (Figure 14). Figure 14 also showed that the mean numbers of the thrips per leaf on Green Oak, Red Oak, and Butter Head were at their highest in May at 12.0, 0.4 and 4.93 thrips, respectively (Appendix Table 2).

Temperature and relative humidity during the study were recorded and the mean temperature, 33.71 ^{O}C, the mean relative humidity, 57.25% RH (Appendix Figure 2).

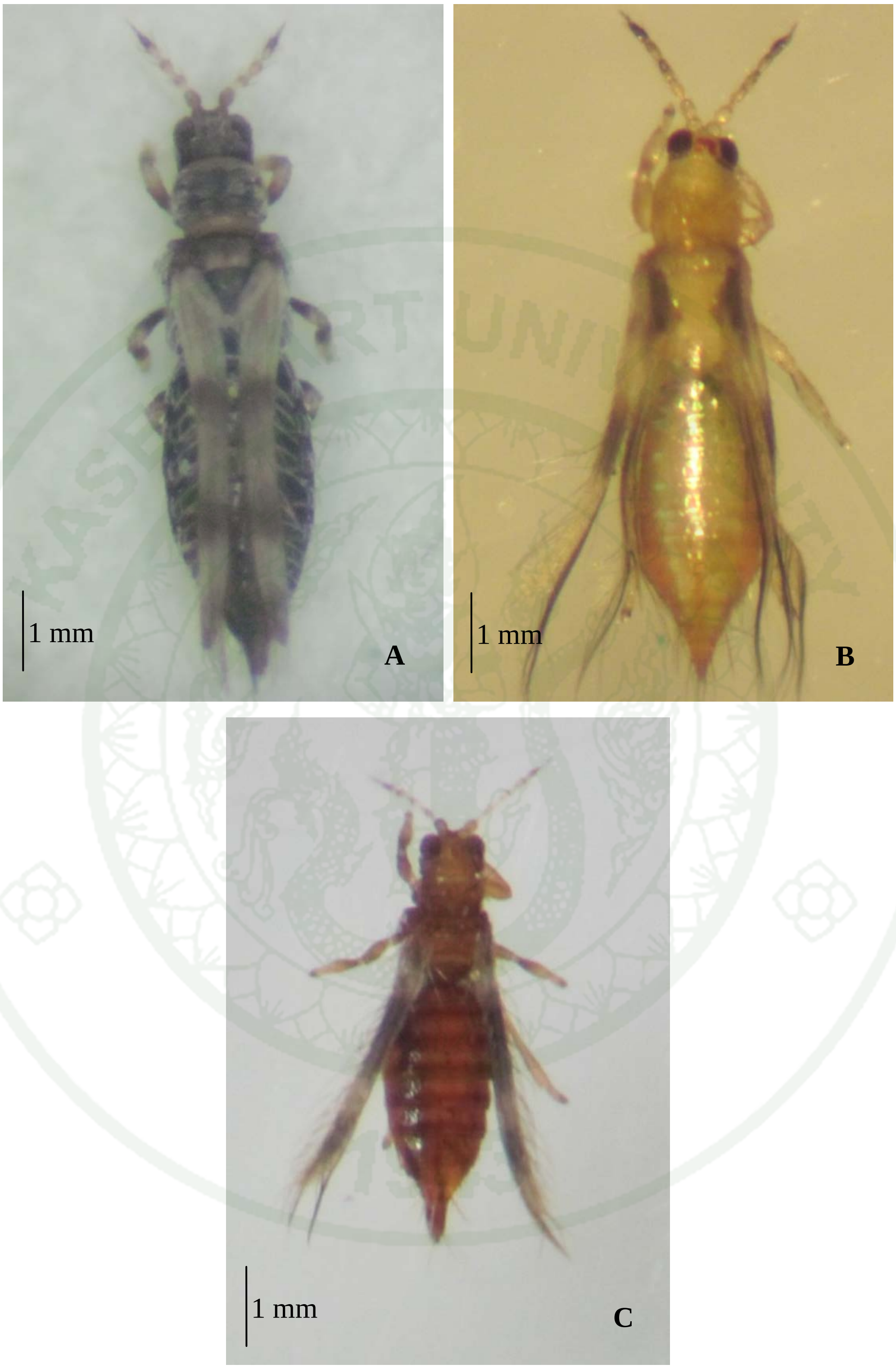

Figure 13 A = *Thrips, Astrothrips globiceps* (Karny)

B = The anthurium thrips *Chaetanaphothrips orchidii* (Moulton)

C = The bean blossom thrips, *Megalurothrips usitatus* (Bagnall)

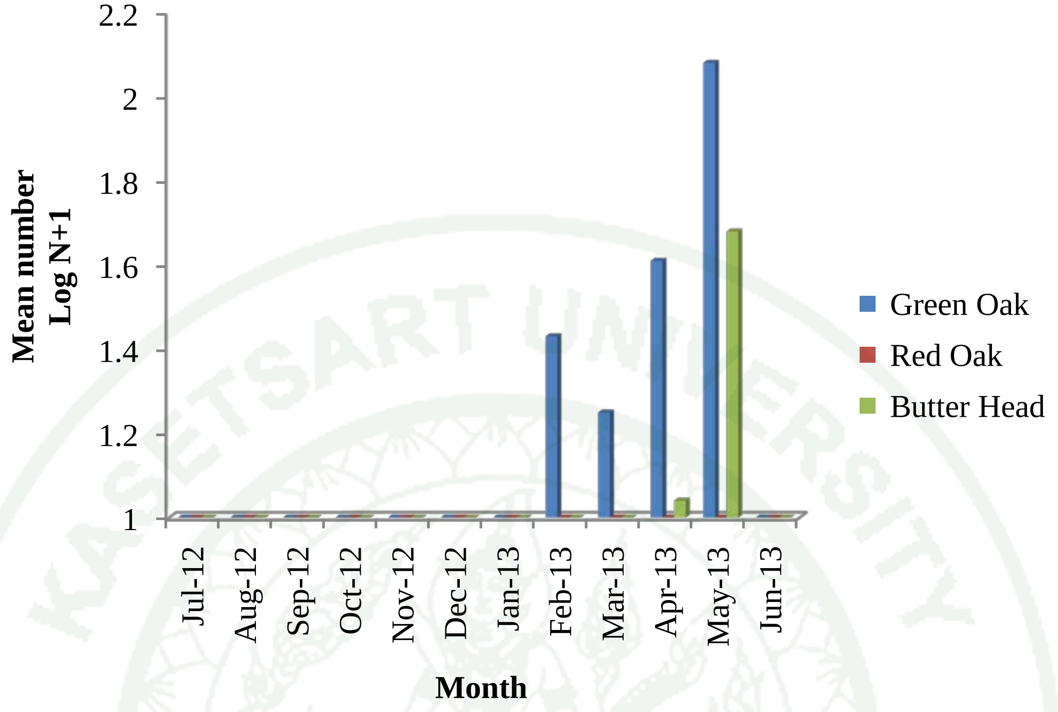

Figure 14 Mean numbers of *Chaetanaphothrips orchidii* (Moulton) per leaf caught in three cultivars of Green Oak, Red Oak and Butter Head grown hydroponically

The variable factors considered that may have affected the thrips, *C. orchidii* population dynamic in the three cultivar of lettuce were temperature and humidity

The correlation coefficient analysis between temperature and population of thrips, *C. orchidii* on Green Oak and Butter Head demonstrated a significant relationship. The coefficients of determination (r^2) were 0.37 (Fig. 15A), 0.32 (Fig. 15C), respectively. The coefficients of determination (r^2) were 0.30-0.49 this indicated a middle relationship thus, temperature and thrips, *C. orchidii* population was in the middle linear relationship. On Red Oak showed that the mean number of thrips, *C. orchidii* was no significant correlation with R^2 values at 0.003 (Fig. 15B). So, population fluctuation of thrips, *C. orchidii* on Green Oak and Butter Head varied depending on the temperature. When the temperature increased, the population of thrips, *C. orchidii* in both cultivars of lettuce also increased. While, the correlation coefficient analysis between the humidity and the thrips population on the same three lettuce cultivars showed that were no significant correlation with R^2 values there, 0.11, 0.037 and 0.09, respectively (Appendix Figure 5).

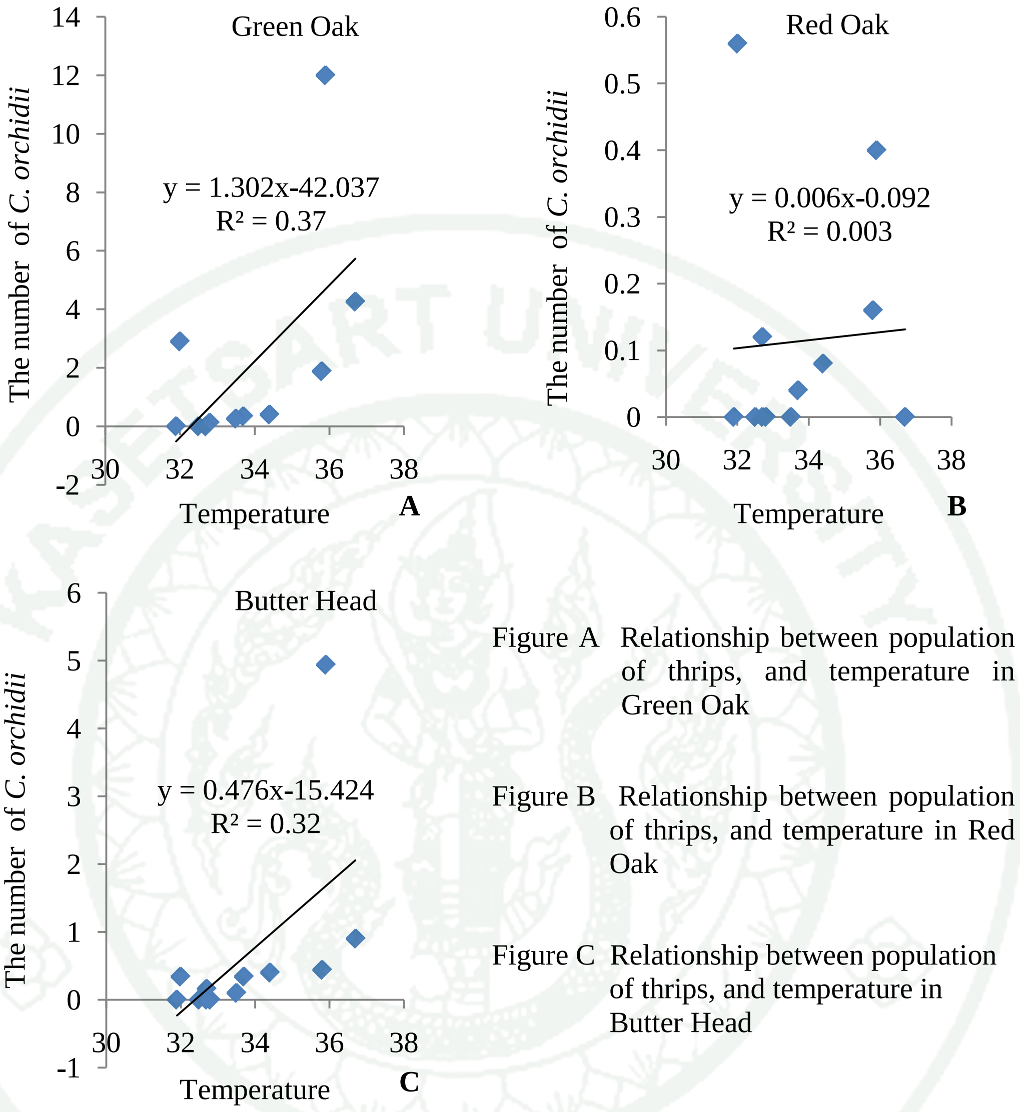

Figure A Relationship between population of thrips, and temperature in Green Oak

Figure B Relationship between population of thrips, and temperature in Red Oak

Figure C Relationship between population of thrips, and temperature in Butter Head

Figure 15 Relationship between the number of the anthurium thrips, *Chaetanaphothrips orchidii* (Moulton) (y) and temperature (x), The straight line regression equation of the number of thrips, *C. orchidii* is y = 1.302x-42.037 (A), 0.006x-0.092 (B) and 0.476x-15.424 (C) (Coefficient of regression = R^2 = 0.37 (A), 0.003 (B) and 0.32 (C), n = 50, $P<0.05$).

2. Spatial distribution pattern of thrips in lettuce

There was no significant difference in the spatial distribution patterns between the upper - and under - side of a lettuce leaf at F = 0.38, *P > 0.05*. However, there were significant differences in the spatial distribution patterns among the three cultivars of Green Oak, Red Oak and Butter Head at F = 9.34, *P<0.01*. The results showed that Green Oak appeared to be a preferred host over Butter Head and then Red Oak. Similarly, there were significant differences found at *P<0.01* among the 6 sampling points on the upper - side (Table 1) and under - side (Table 2) of a leaf at F = 5.65 and 4.21, respectively. On the upper-side of a Green Oak leaf, Sampling Point #3 appeared to be the most preferred site of distribution for the thrips, followed equally by #1, 2, 4, 5, and 6. On the under - side of a Green Oak leaf, Sampling Point #5 appeared to be the most preferred site of distribution for the thrips, followed equally by #1, 2, 3, 4, and 6.

Table 1 Mean number of *Frankliniella schultzei* (Trybom) found at the 6 sampling points on the upper - side of a lettuce leaf of three cultivars; Green Oak, Red Oak and Butter Head, grown hydroponically in a greenhouse

Upper - side of a lettuce leaf	The mean number of *F. schultzei*[1/]					
	Green Oak		Red Oak		Butter Head	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1. the mid rib of the apex	1.00[b2/]	0.00	1.00[b]	0.00	1.00[b]	0.00
2. the mid rib of the middle	1.02[b]	0.08	1.00[b]	0.00	1.03[b]	0.10
3. the mid rib of the base	1.07[a]	0.14	1.00[a]	0.08	1.06[a]	0.13
4. the margin of the apex	1.00[b]	0.00	1.00[b]	0.00	1.00[b]	0.00
5. the margin of the middle	1.01[b]	0.04	1.00[b]	0.00	1.00[b]	0.00
6. the margin of the base	1.00[b]	0.00	1.00[b]	0.00	1.01[b]	0.04

[1/]Transformation by using LogN+1

[2/]Mean within column followed by different letters is significantly different by Turkey's Range Test (P<0.01)

Table 2 Mean number of *Frankliniella schultzei* (Trybom) found at the 6 sampling points on the under - side of a lettuce leaf of three cultivars; Green Oak, Red Oak and Butter Head, grown hydroponically in a greenhouse

Under - side of a lettuce leaf	The mean number of *F. schultzei*[1/]					
	Green Oak		Red Oak		Butter Head	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1. the mid rib of the apex	1.02[b2/]	0.08	1.00[NS]	0.00	1.00[b]	0.00
2. the mid rib of the middle	1.00[b]	0.00	1.00	0.00	1.03[b]	0.10
3. the mid rib of the base	1.01[a]	0.04	1.00	0.08	1.05[a]	0.13
4. the margin of the apex	1.01[b]	0.04	1.00	0.00	1.00[b]	0.00
5. the margin of the middle	1.06[b]	0.17	1.00	0.00	1.00[b]	0.00
6. the margin of the base	1.01[b]	0.04	1.00	0.00	1.01[b]	0.04

[1/]Transformation by using LogN+1

[2/]Mean within column followed by different letters is significantly different by Turkey's Range Test (P<0.01)

NS = Mean within column not significantly different (P>0.01)

The mean numbers of the thrips on each of the 7 leaves from each of Green Oak, Red Oak and Butter Head were counted and recorded in January to March 2013. The results showed that the mean numbers of the thrips on the 1st leaf were not significant at $P>0.05$ on Green Oak, Red Oak and Butter Head at F = 0.16, 0.28 and 0.16 thrips/leaf, respectively. However, the mean numbers were significantly different at $P<0.01$ on the 2nd through 7th leaf on Green Oak, Red Oak and Butter Head (Table 3). Among all the 7 leaves sampled, the mean number of the thrips per leaf was found the highest on the 3rd leaf of Green Oak and Red Oak. The mean number of the thrips per leaf on the 1st leaf of all three cultivars was lower than other leaves in the same lettuce head, except the 7th leaf where there was no thrips found on cultivars Red Oak and Butter Head (Table 3).

Table 3 Mean number of *Frankliniella schultzei* (Trybom) found on each of the 7 leaves of three cultivars Green Oak, Red Oak and Butter Head, grown hydroponically in a greenhouse at Kamphaeng Saen District, Nakhon-Pathom Province, during January to March 2013

Mean number of thrips[1/]	Lettuces						CV	F
	Green Oak		Red Oak		Butter Head			
	Mean	S.D.	Mean	S.D.	Mean	S.D.		
1st leaf	$1.01^{NS42/}$	0.09	1.01^{23}	0.06	1.00^{34}	0.00	17.50	2.818
2nd leaf	$1.03^{a3/23}$	0.12	1.04^{a1}	0.12	1.00^{b23}	0.00	12.06	12.495
3rd leaf	1.07^{a2}	0.17	1.08^{bc1}	0.20	1.03^{c12}	0.11	11.68	5.874
4th leaf	1.13^{a1}	0.22	1.00^{c23}	0.00	1.03^{b1}	0.10	10.46	11.715
5th leaf	1.08^{a2}	0.17	1.01^{b2}	0.06	1.01^{b123}	0.06	13.46	11.715
6th leaf	1.02^{a3}	0.09	1.00^{b23}	0.00	1.01^{b34}	0.07	18.70	5.920
7th leaf	1.03^{a34}	0.12	1.00^{b3}	0.00	1.00^{b4}	0.00	25.71	3.540
CV	7.22		11.76		10.00			

[1/]Transformation by using LogN+1

[2/]Mean within column followed by different numbers is significantly different by Turkey's Range Test (P<0.01)

[3/]Mean within row followed by different letters is significantly different by Turkey's Range Test (P<0.01)

NS = Mean within row not significantly different (P>0.05)

The dispersion patterns of the thrips on the three cultivars of lettuce; Green Oak, Red Oak and Butter Head, were estimated by using $S^2/\bar{x}$ and $t=\frac{S^2/\bar{x}-1}{S_{\bar{x}}}$. Any absolute value at t >1.96 indicated a distribution that differs from random with a certainty of 95%. Results of the study showed that the thrips had a uniform distribution on Green Oak and Red Oak and a clumped distribution on Butter Head (Table 4)

Table 4 Dispersion patterns of *Frankliniella schultzei* (Trybom) on three cultivars of lettuce grown hydroponically in a greenhouse at Kamphaeng Saen District, Nakhon Pathom Province, during January to March 2013

Lettuces	$S^2/\overline{x}$	t	distribution
Green Oak	0.98	-0.08^{NS}	uniform
Red Oak	0.27	-8.10^{NS}	uniform
Butter Head	1.28	1.23^{NS}	clumped

NS = not significantly different (P>0.05) by Turkey's Range Test.

3. Predators's effectiveness and role when releasing one species and combination under laboratory and hydroponics cultivation

3.1 Killing capacity of predators on thrips under laboratory

Killing capacity of the three predators, *M. basalis*, *W. rotunda* and *O. maxidentex* were significant (P<0.05). The second instar of *M. basalis* had the most killing capacity, the mean number of thrips, *F. schultzei* eaten was 26.40±3.75 thrips/day (Table 5). Followed by the third instar of *O. maxidentex* and *W. rotunda*, the mean number of thrips, *F. schultzei* eaten was 16.40±1.43 and 13.00±2.49 thrips/day, respectively. The first instar of *W. rotunda* had the least killing capacity, the mean number of thrips, *F. schultzei* eaten was 16.40±1.43 thrips/day.

Table 5 Mean number of *Frankliniella schultzei* (Trybom) eaten by three predators, *Mallada basalis* (Walker), *Wollastoniella rotunda* Yasunaga& Miyamoto and *Orius maxidentex* Ghauri under laboratory (25±2^{O}C and 55±2 % RH)

Predators	Instars	The mean number of *F. schultzei* eaten[1/] Mean	S.D.	Range
M. basalis	1	7.60^{f}	1.20	6-8
	2	26.40^{a}	3.80	21-30
	3	9.90^{def}	6.56	0-18
W. rotunda	1	4.70^{g}	4.00	0-11
	2	7.70^{f}	1.34	6-9
	3	13.00^{cd}	2.49	9-16
	4	12.10^{cde}	4.68	4-18
	5	9.40^{ef}	4.65	5-18
	Adult	11.50^{cde}	2.27	9-15
O. maxidentex	1	9.80^{def}	2.20	7-13
	2	10.90^{cde}	0.74	10-12
	3	16.40^{b}	1.43	14-18
	4	12.30^{cde}	1.16	11-14
	5	11.30^{cde}	2.35	8-14
	Adult	13.40^{c}	1.27	11-15

[1/] Mean within column followed by different letters is significantly different (P>0.05) by Turkey's Range Test

Considering the killing capacity on thrips, *F. schultzei* of each instar of predator, the second instar of *M. basalis*, the third instar of *W. rotunda* and *O. maxidentex* had the highest killing capacity.

Killing capacity comparison of the three predators on *F. schultzei* by orthogonal comparison (Gomez and Gomez, 1984), all instar, early larvae instar (The first and the second instar) and late larvae instar (The third to the fifth instar) of the three predators were significant (P<0.05).

All instar and early larvae instar of *M. basalis* had the highest killing capacity of *F. schultzei*. The mean number of *F. schultzei* remaining were 14.63±9.52 and 17.00±10.02 thrips/day respectively but late larvae instar, *O. maxidentex* had the most killing capacity on *F. schultzei*, the mean number of *F. schultzei* remaining was 13.33±2.79 thrips/day (Fig. 16).

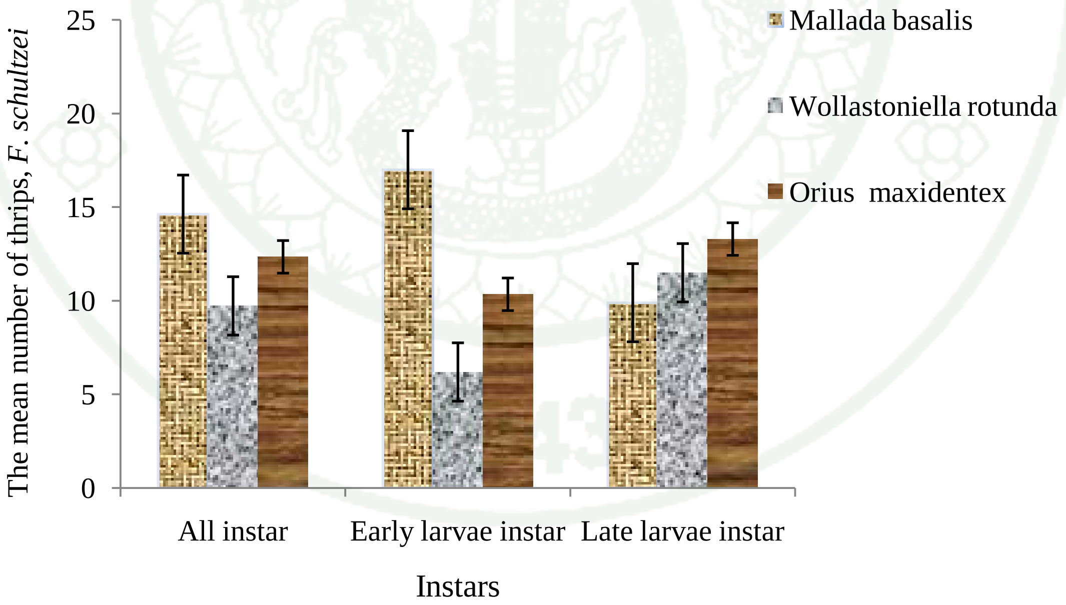

Figure 16 Orthogonal comparisons of killing capacity on *Frankliniella schultzei* (Trybom) of three predators, *Mallada basalis*(Walker), *Wollastoniella rotunda* Yasunaga& Miyamoto and *Orius maxidentex* Ghauri

3.2 Predators's effectiveness and role when releasing one species and combination under laboratory conditions

There were significant differences in 3 predators when without interspecific competition - 1 species was released (Table 6), found at F = 62.49, *P<0.01*. Similarly to the 2nd group; consisted of 2 predators released at the different times during a 24 hours period (Table 7) and the 3rd group; consisted of 2 predators released at the same time (Table 8) at F =, 21.97 and 15.27, respectively.

In the 1st group; without interspecific competition - 1species was released, in treatment 1; releasing *M. basalis* appeared to be the highly effective agents of *F. schultzei*, followed equally by in treatment 2; releasing *W. rotunda* and 3; releasing *O. maxidentex* (Table 6). In the 2nd group; consisted of 2 predators released at the different times during a 24 hours period, in treatment 4; releasing *M. basalis* and *W. rotunda* and 6; releasing *W. rotunda* and *M. basalis* appeared to be the highly effective agents of *F. schultzei*, followed equally by in treatment 5, 8, 9, and 7 (Table 7). In the 3rd group; consisted of 2 predators released at the same time, in treatment 10; releasing *M. basalis* and *W. rotunda* and 11; releasing *M. basalis* and *O. maxidentex* appeared to be the highly effective agents of *F. schultzei*, followed equally by in treatment 12 (Table 8).

The results of the fourth group in treatment 13; three predators, *M. basalis*, *W. rotunda* and *O. maxidentex* released together and the fifth group in treatment 14; an untreated control in which no predator were released (Control treatment) shown in Table 9.

Table 6 Mean number of *Frankliniella schultzei* (Trybom) were remaining after released predators in the 1st group; 1 species of 3 predators; *Mallada basalis* (Walker), *Wollastoniella rotunda* Yasunaga& Miyamoto and *Orius maxidentex* Ghauri were released under laboratory (37±2 °C and 55±2 % RH)

The 1st group; 1 species was released	Mean number of *F. schultzei* were remaining[1/]		
	Mean	S.D.	Range
1. *M. basalis*	15.71[a2/]	0.13	6-50
2. *W. rotunda*	16.02[b]	0.12	48-72
3. *O. maxidentex*	16.30[c]	0.14	66-89
CV	11.20		

[1/]Transformation by using SQRT X+1

[2/]Mean within column followed by different letters is significantly different by Turkey's Range Test (P<0.01)

Table 7 Mean number of *Frankliniella schultzei* (Trybom) were remaining after in the 2nd group; consisted of 2 predators were released at the different times during a 24 hours period under laboratory (37±2 ^{O}C and 55±2 % RH)

The 2nd group; 2 predators were released at the different times during a 24 hours period	Mean number of *F. schultzei* were remaining[1/]		
	Mean	S.D.	Range
4. *M. basalis - W. rotunda*	15.71[a2/]	0.22	2-58
5. *M. basalis - O. maxidentex*	16.34[b]	0.04	10-55
6. *W. rotunda - M. basalis*	15.85[a]	0.21	6-49
7. *W. rotunda - O. maxidentex*	16.85[c]	0.22	30-56
8. *O. maxidentex - M. basalis*	16.53[bc]	0.08	5-60
9. *O. maxidentex - W. rotunda*	16.71[bc]	0.15	10-61
CV	6.50		

[1/]Transformation by using SQRT X+1

[2/]Mean within column followed by different letters is significantly different by Turkey's Range Test (P<0.0)

Table 8 Mean number of *Frankliniella schultzei* (Trybom) were remaining after in the 3rd group; consisted of 2 predators were released at the same times under laboratory (37±2 ^{O}C and 55±2 % RH)

The 3rd group; 2 predators were released at the same times	Mean number of *F. schultzei* were remaining[1/]		
	Mean	S.D.	Range
10. *M. basalis* - *W. rotunda*	15.77[a2/]	0.05	0-13
11. *M. basalis* - *O. maxidentex*	15.47[a]	0.18	2-16
12. *W. rotunda* - *O. maxidentex*	16.47[b]	0.34	5-6
CV	10.00		

[1/]Transformation by using SQRT X+10

[2/]Mean within column followed by different letter is significantly different by Turkey's Range Test (P<0.01)

Table 9 Mean number of *Frankliniella schultzei* (Trybom) were remaining after in the 4th group, three predators released together and in the 5th group; an untreated control in which no predator were released (Control treatment) under laboratory (37±2 ^{O}C and 55±2 % RH)

Groups	Mean number of *F. schultzei* were remaining[1/]		
	Mean	S.D.	Range
The 4th group; 3 predators released together			
13. *M. basalis* - *W. rotunda* - *O. maxidentex*	17.56	1.03	42 - 73
The 5th group; an untreated control			
14. No predator	19.27	0.28	80 - 90

[1/]Transformation by using SQRT X+10

3.3 Predators's effectiveness and role when releasing one species and combination under hydroponics cultivation

Effect of 3 predators *M. basalis*, *W. rotunda* and *O. maxidentex* on *F. schultzei* populations: The 4 treatments of releasing 3 predators; 1) one species was released, *M. basalis*, 2) releasing *M. basalis* and *W. rotunda* at the different times during a 24 hours period, 3) releasing *M. basalis* and *W. rotunda* at the same time and 4) releasing *M. basalis*, *W. rotunda* and *O. maxidentex* together was effective in reducing the *F. schultzei* population inhabiting leave of Green Oak. On the 1st week after 3 predators released, mean numbers of *F. schultzei* in various treatment were significant differences from the control treatment (an untreated control in which no predator were released) at F = 31.305, $P < 0.01$ (Table 10). Similar results were obtained for subsequent releasing done on the 2nd, 3rd, and 4th week at F = 136.375, 431.85 and 1294.806, $P < 0.01$, respectively. During the study, the number of *F. schultzei* was less in treatment treated with predators than control treatment on each week (Table10).

Among all the 4 treatment of releasing predators from the 1st week to 4th week, the mean number of *F. schultzei* was found the least in treatment 1; one species was released, *M. basalis*. Similar results were shown in treatment 4; releasing *M. basalis*, *W. rotunda* and *O. maxidentex* together (Table 10).

Table 10 Mean number of *Frankliniella schultzei* (Trybom) after releasing three predators with 5 treatments; 1) releasing *M. basalis*, 2) Releasing *M. basalis* and *W. rotunda* at the different times during a 24 hours period, 3) releasing *M. basalis* and *W. rotunda* at the same time 4) releasing *M. basalis, W. rotunda* and *O. maxidentex* together and 5) an untreated control in which no predator were released (Control treatment) under hydroponics cultivation (37±2 ^{O}C and 55+2 % RH)

Treatments	Mean number of *F. schultzei* were remaining[1/]							
	1st week		2nd week		3rd week		4th week	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	22.00^{a}	2.00	26.34^{a}	1.52	11.33^{a}	1.52	12.34^{a}	0.57
2	38.33^{c}	4.04	46.30^{b}	3.05	19.35^{bc}	2.08	19.70^{b}	0.60
3	31.33^{b}	1.15	54.60^{c}	1.52	21.67^{c}	1.54	20.00^{b}	2.64
4	23.33^{a}	3.51	29.40^{a}	1.52	15.60^{b}	3.05	10.33^{a}	0.60
5	42.66^{c}	2.30	49.00^{b}	1.00	67.00^{d}	0.57	81.67^{c}	1.60
CV	7.13		7.34		10.07		14.79	

[1/]Mean within column followed by different letter is significantly different by Turkey's Range Test (P<0.01)

Control efficiency percentage analysis after releasing three predators with 4 treatments. There were significant differences in the 1st week to the 4th week at F= 18.26, 23.45, 36.11 and 22.90, P<0.01 (Figure 17). Among all the 4 treatment of releasing predators, treatment 1; releasing *M. basalis* showed the highest control efficiency of *F. schultzei* 45.10%, 46.00%, 82.67% and 84.25% in the 1st, 2nd, 3rd and 4th week, respectively.

Considering releasing predators between one species and combination, the results shown that releasing one species in treatment 1, had the the highest control efficiency of *F. schultzei* more than releasing combination in treatment 2; Releasing *M. basalis* and *W. rotunda* at the different times during a 24 hours period, 3; releasing *M. basalis* and *W. rotunda* at the same time and 4; releasing *M. basalis*, *W. rotunda* and *O. maxidentex* together. However, control efficiency of *F. schultzei* was no significant differences in treatment 1 and treatment 2 (Figure 17).

Figure 17 showed that the 1st week except in treatment 3 and 4, control efficiency of *F. schultzei* were negative -48.88% and -24.16%, respectively. Similarly result was shown in the 2nd week except in treatment 4; -15.57%. Then control efficiency of *F. schultzei* was increased in the 3rd and 4th week.

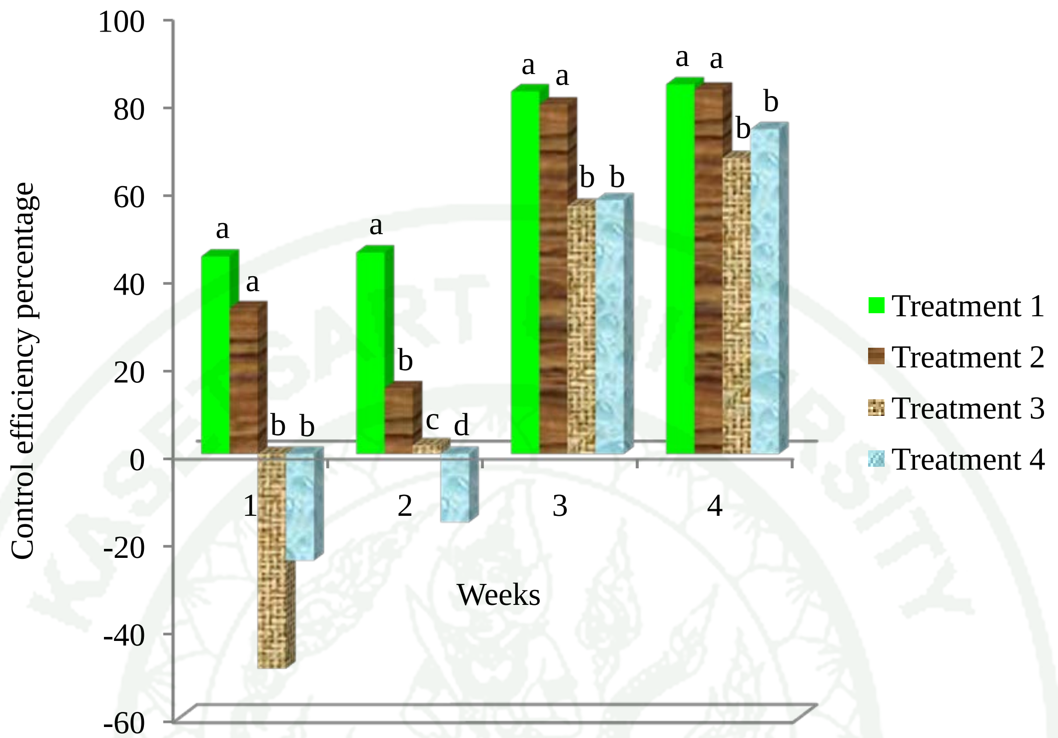

Figure 17 Control efficiency percentage on *Frankliniella schultzei* (Trybom) of three predators with 4 treatments; 1) releasing *M. basalis*, 2) Releasing *M. basalis* and *W. rotunda* at the different times during a 24 hours period, 3) releasing *M. basalis* and *W. rotunda* at the same time 4) releasing *M. basalis*, *W. rotunda* and *O. maxidentex* together under hydroponics cultivation (37±2 ^{O}C and 55$\underline{+}$2 % RH)

Discussions

1. Population fluctuation of thrips in lettuce under hydroponic cultivation

1.1 Population fluctuation of thrips in Muang District, Pathum-Thani Province

F. schultzei was commonly found on lettuce throughout the year in Thailand, causing serious damage to lettuce. The presence of *F. schultzei* on cultivars Iceberg Lettuce, Red Salad Bowl and Red Rapid used as the test plants in this study indicates that lettuce leaves serve as an important nutritional source for the development of the thrips. It was reported that the nutritional quality of a plant is an important factor affecting the host selection of thrips (Brodbeck *et. al*., 2002). Lettuce leaves are known to contain high nutritional contents, which provide high concentrations of amino acids that are then converted into proteins to sustain the rapid growth of immature thrips (Brodbeck *et. al*., 2001). Among the nutrients required for the growth of thrips, carbohydrates were reported to have stimulated feeding from thrips and increased their food consumption (Scott Brown *et. al*., 2002). Results of the population dynamics study on *F. schultzei* on three cultivars of lettuce planted monthly in January – August 2012 showed that the thrips was not present on the lettuce in January and February plantings; however, its populations quickly built up in March planting and then crushed in April planting. The cause for the thrips population buildup in March planting and decline in April planting is not exactly known. However, one possible cause is that as the growth of lettuce leaves reduces with the increase of temperature, their leaf textures become more fibrous, thicker, and bitter in taste (Wolford and Banks, 2009); thus, are less preferred for feeding by the thrips. During this study, the temperatures in the greenhouse in March were in the range of 24.2 – 37.7^{o} C, which appears to be most suitable for the thrips to grow. However, the temperature rose in April to the range of 32.8 – 47^{o} C, causing a sharp decline of the thrips populations on lettuce due to the change of its leaf textures, which impacts on the survival of the thrips. Since the thrips populations on the three cultivars of lettuce reach their peaks in the March planting, it suggests that efforts be made by lettuce growers not to plant lettuce in the month of March to avoid damage caused by the thrips.

The relative humidity recorded at one of the study sites in Pathum Thani were maintained at relatively constant around 95% in the greenhouse. Therefore, it can be expected that the relative humidity have no effect on the population dynamics of *F. shultzei* under the greenhouse conditions. The temperature, however, increased from 37.7 to 47^{o} C in April and 44^{o} C in August. This change of the temperature apparently has no significant effect on the population fluctuations of *F. shultzei* in the greenhouse either. This is consistent with the finding that temperature has a minimal effect on the population fluctuations of *F. occidentalis* and *T. palmi* on orchids under the greenhouse conditions in Singapore (Liansheng *et al.*, 2013). Contrary to the findings in the greenhouse, temperature was reported to be an important factor affecting the abundance of thrips, which caused economic damage to the nectarine crops in open field conditions in Turkey in March and April (Atakan and Uygur, 2004; Hazir and Ulusoy, 2012).

Among the three cultivars of lettuce tested, *F. schultzei* was found to be most abundance on Iceberg Lettuce, followed by Red Salad Bowl and then Red Rapid. The highest population count found on Iceberg Lettuce suggests that it has a mild flavor and a firm crunchy texture, which appears to be preferred by thrips (Wolford and Banks, 2009). Based on this study, Red Rapid was the least preferred among the three cultivars as it was reported to be resistant to disease, insect and climate (Miles *et al.*, 2005).

1.2 Population fluctuation of thrips in Kamphaeng Saen District, Nakhon-Pathom Province

Results from this study showed that three thysanopterous insect species were eventually collected from three cultivars of lettuce including Green Oak, Red rapid and Butter Head, They were thrips, *A. globiceps*, *C. orchidii* and *M. usitatus*. Thrips, *C. orchidii* were the most found in three cultivars of lettuce more than two species. Thrips, *C. orchidii* has been detected in lemon, citrus and orchards in Northwest Argentina, central and south central of Florida. They were found to cause rind blemish damage (ring spot) on citrus and red grapefruit varieties. Moreover in 1926, they have become a common pest of orchid anthurium and ornamentals in South America, Australia, Japan, Hawaii, India and within the USA (Childers and Frantz, 1994; Hara *et al*., 2002; Childers and Nakahara, 2006; Goane *et al*., 2013). Another thrips species, *M. usitatus* has been detected in sun flower in Anantapur, Kurnool, Mahabubnagar and Ranga Reddy district of Andhra Pradesh (Bhat *et al*., 2012). This study showed that in addition to citrus, lemon and orchid, *C. orchidii* could be destroyed lettuce.

Considering the destruction caused by *C. orchidii* in the three cultivars of lettuce Green Oak was the most destroyed because the leaves are very attractive, distinctively lobed, loosely bunched leaves, soft, thin and crispy (Wolford and Banks, 2009). While Red Oak, the leaf has similar to Green Oak but it has thicker than Green Oak. Butter Head, the outer leaves are large and ruffled, often loosely folded with soft and tender leaves. Two cultivars of lettuce, Red Oak and Butter Head when temperature was increased, leaf growth was reduced. The leaf has fiber, thicker and bitter taste. This study temperature was conducted at 33.71 ^{O}C, so this is the reason why the destruction caused by *C. orchidii* in Red Oak and Butter Head was the most destroyed than Green Oak.

Comparison the variable factors and population of *C. orchidii* showed that population of *C. orchidii* in three cultivars of lettuce vary depending on temperature. As the temperature increased, the *C. orchidii* population increased. Similar to *F. occidentalis* (Pearsall, 2002; Rhainds *et al*., 2007), *S. dorsalis* in Chennai (Ananthakrishnan *et al*., 1982), *F. fusca* and *T. tabaci* (Morsello S. C. *et al*., 2008). Temperature are important factors that affect the population dynamic, distribution pattern and functional response of *S. longicornis* on two spotted spider mite (Pakyari *et al*., 2009; Zhang *et al*., 2005) but Bagle (1993) reported that temperature and humidity were correlated negative to leaf curl of chili cause by thrips.

2. Spatial distribution pattern of thrips in lettuce

It is interesting that results of the spatial distribution study showed no significant difference in the mean number of *F. schultzei* per leaf between the upper-side and under-side of a leaf. This seems to show that thrips may not have preference in their feeding on upper-side or under-side of a leaf as it was reported that adults of *Parthenothrips dracaenae* and *F. occidentalis* mostly prefer on the upper-side of the leaf; however, larvae of *P. dracaenae and Echinothrips americanus* prefer on the under-side of the leaf (Entocare, 2013). The density of trichomes on a leaf and softness of leaf tissues can affect the spatial distribution of *T. tabaci* (Duchovskiene, 2006).

Results of the study on the relative abundance of *F. schultzei* at the six sampling points each on the upper-side and under-side of a lettuce leaf showed that *F. schultzei* was most abundant at Sampling Point #3 on the upper-side of the leaves of all three lettuce cultivars. On the under-side of the leaves of the three cultivars of lettuce, *F. schultzei* was most abundant at Sampling Point #5 on Green Oak and Red Oak and at Sampling Point #3 on Butter Head only. The reason for the differences in the relative abundance at different sampling points of a leaf is not known; however, *F. schultzei* appears to prefer colonizing at the mid-rib of the base and the outer margin of a lettuce leaf.

The distribution pattern study illustrates that *F. schultzei* has a uniform distribution pattern on Green Oak and Red Oak, while it has a clumped or aggregated distribution pattern on Butter Head. It was reported that *F. schultzei* possess both aggregated and random to regular distribution patterns on cucumber (Kakkar, 2010). In addition, *F. schultzei* was observed to have an aggregated distribution pattern on flower of corolla of *Hibiscus rosasinensis* and *Gossypium hirsutum* (Milne *et al*., 2002) and on flower of blueberry (Arevalo *et al.*, 2009). Similarly, *F. occidentalis* was reported to have an aggregated distribution pattern on orchid (Liansheng *et. al.*, 2013) and on cucumber and green bean (Cho *et al*., 2001; Deligeorgidis, 2002; Mateus *et. al*., 2005).

3. Predators's effectiveness and role when releasing one species and combination under laboratory and hydroponics cultivation

3.1 Killing capacity of predators on thrips under laboratory

In this study, the second instar of *M. basalis* had the most killing capacity follow by the third instar of *O. maxidentex*; the first instar of *W. rotunda* had the least killing capacity. The killing capacity of the predator in order Neuroptera, family Chrysopidae, it has been reported that *M. basalis* larvae exhibited little or no preference for the different life stages of the two mites, *Tetranychus kanzawai* Kishida and *Panonychus citri* (McGregor). That is, all three lacewing instar accept all T. *kanzawai* life stages equally and that for *P. citri*, first instar lacewing do not accept adults at as high a rate as eggs and larvae (Cheng *et al*., 2009; Cheng *et al*., 2010). The green lacewing, *Chrysoperla carnae* (Stephens) larvae do not display a preference for the first and second instar thrips, *S. perseae* (Hoddle and Robinson, 2004) but *C. rufilabris* Burmeiste larvae exhibit a preference for either the first or second instar *S. perseae* larvae (Silvers, 2000). The killing capacity of predator in order Hemiptera, family Anthocoridae, it has been reported that an invasive anthocorid, *Montandoniola confuse* (=moraguesi) Streito and Matocq sp. nov. (Heteroptera: Anthocoridae) preferred the eggs of the weeping fig thrips, *Gynaikothrips uzeli* Zimmerman (Thysanoptera: Phlaeothrip) 92% and 94% of all prey taken in no choice and choice tests, respectively. Females of this predator species consume significantly more eggs than males 83% and 91% per 48 hours period, respectively (Arthurs *et al*., 2011). A commercially available anthocorid, *O. insidiosus* Say (Heteroptera: Anthocoridae) prefers larval thrips (Bacz *et al.*, 2004) and kills primarily the first instar larvae of *F. occidentalis* (Wimmer *et al*., 2008) but Chow *et al*. (2010) reported that males and females of *O. insidiosus* do not show preference to adult thrips *F. occidentalis* and the third instar of *O. maxidentex* are the most consumed at 38.00±4.50 thrips/day (Kaewpradit, 2010).

3.2 Predator's effectiveness and role when releasing one species and combinations under laboratory

There are three predators of the thrips, they are the green lacewing, *M. basalis* (Hoddle and Robinson, 2004) and two anthocorid bugs, *W. rotunda* and *O. maxidentex* (Lattin, 2000; Gitonga *et al*., 2002; Premachandra and Borgemeister, 2003; Shipp and Wang, 2003). The results shown that there were significant differences of releasing 3 predators between one species and combination when compared with an untreated control. In this study the mean number of thrips, *F. schultzei* did not increase in an untreated control, they also decreased. However, the mean number of thrips, *F. schultzei* surviving was more than when releasing three predators. This indicates that the environment inside plastic containers was not suitable for Thrips development or reproduction. Another study, Cheng *et al*. (2012) compared population suppression of the *T. kanzawai* and *P. citri* on papaya by the second instar larvae of M. basalis with various predator: prey release ratio in the laboratory. After three days, predator: prey ratios of 1:30, 1:15 and 1:10 resulted in a reduction of *T. kanzawai* 66.8%, 82.6% and 83.3%, respectively and a reduction of P. citri 41.8%, 75.5% and 77.2%, respective. Total mite reduction for both mite species present was 48.5%, 71.9%, and 74.5% at a ratio of 1:30, 1:15 and 1:10, respectively; a predator: prey ratio of 1:15 produced the greatest reduction. Dogramaci *et al.* (2011) examined the biological control of chilli thrips with *A. swirskii* and *O. insidiosus*. Laboratory tests showed that at equivalent rates, *O. insidiosus* was a more effective predator of adult thrips compared with *A. swirskii*, at a rate of 20 predators per infested pepper plant, both predator species maintained 60.5 thrips per leaf and <1% foliar damage after five weeks.

3.3 Predator's effectiveness and role when releasing one species and combinations under hydroponics cultivation

Predator's effectiveness; *M. basalis*, *W. rotunda* and *O. maxidentex* on *F. schultzei* populations when releasing one species and combinations. The results were shown that they can control *F. schultzei* populations and the mean number of

F. schultzei was always less than in the untreated control. This result is similar to the study of Chow *et al*. (2010) who compared the control of *F. occidentalis* on rose by releasing only *A. swirskii* or both *O. insidiosus* and *A. swirskii*. A rose without predators had, on average, two to three times more thrips than a rose with predators. Concurrent releases of *O. insidiosus* with *A. swirskii* did not appear to either interfere with or enhance the suppression of *F. occidentalis* on cut roses. Dogramaci *et al*. (2011) examined biological control of chili thrips, *S. dorsalis* with *A. swirskii* and *O. insidiosus*. Plants treated with *O. insidiosus* alone or in combination with *A. swirskii*, shown that both predators are effective predators of *S. dorsalis* on pepper and suggests that both species can be used in combination without decreased efficacy through intraguild predation. Weintraub *et al.* (2011) released *O. laevigatus* at different rates, with and without simultaneous release *A. swirskii* for thrips control. There was no significant difference in the quality or quantity of the pepper yield between treatments in which either 2 or 6 orius/m^2 or Orius plus *A. swirskii* were released. Releasing both predators of *O. insidiosus* and *A. degenerans* did not enhance control of *F. occidentalis* compared with *O. insidiosus* alone, because *O. insidiosus* tended to switch to the most abundant prey and thus is an intra-guild of *A. degenerans* (Chow *et al*., 2008). As all *C. carnea* larvae instars attack the first instar predator thrips, *F. orizabensis* Johansen (Thysanoptera: Aeolothripidae). Second instar of *C. carnea* engage in the highest levels of intraspecific predation (Hoddle and Robinson, 2004).

Releasing one species, *M. basalis* showed the highest control efficiency of *F. schultzei*. While releasing combinations, the highest control efficiency of *F. schultzei* were shown when releasing *M. basalis* and *W. rotunda* at the different times during a 24 hours period.

In this study in the 1st week found that except in treatment 3 and 4, control efficiency of *F. schultzei* were negative. Similarly result was shown in the 2nd week except in treatment 4. It assump that adverse interactions among natural enemies were occurred.

This study can assist the hydroponic farmers when attempting to control an outbreak of thrips, *F. schultzei*. The farmer can use the three predators, *M. basalis*, *W. rotunda* and *O. maxidentex* for pest control. There are four methods for releasing predator, releasing one predator, two predators at the different time, two predators at the same time or three predators together. The use of multiple natural enemy species has been promoted, in part, as a strategy to enhance the management of pest complex in a greenhouse agro ecosystems. With this strategy, two or more species of natural enemies are added to a pest-crop system, an advocate was asked which combination is the most effective against the pest population; the more effective combinations of natural enemies would ideally reduce the total numbers required for affectations and timely pest suppression, and reduce overall production costs. In constructing natural enemy combinations, it is hoped that adverse interspecific interactions among natural enemies are kept to a minimum while natural enemy-pest interactions are optimized (Rott and Ponsonby, 2000: Schausberger and Walzer, 2001: Chow *et al*., 2008; Calvo *et al*., 2009)

CONCLUSION

Growing lettuce hydroponically in a greenhouse has become popular in Thailand. However, damage caused by *F. shcultzei* remains to be a challenge to lettuce growers. Considering the population dynamics, spatial distribution and distribution patterns of *F. schultzei*, lettuce growers are recommended to grow Red Rapid and Red Oak, instead of Iceberg Lettuce and Green Oak. Unfortunately, Iceberg Lettuce and Green Oak are two popular cultivars grown in Thailand. As such, to minimize the damage caused by *F. schultzei*, growers are recommended not to plant Iceberg Lettuce and Green Oak in February, March, May, June, July and August when the thrips population was most abundant. Rather, lettuce, regardless of cultivars, should be planted in January when the population of *F. schultzei* is low.

Hydroponics farmers could formulate a strategy to control thrips populations when the outbreak of *F. schultzei* occurrs biological control agents can be used against thrips, *F. schultzei*, thus reducing or eliminating product damage**.**

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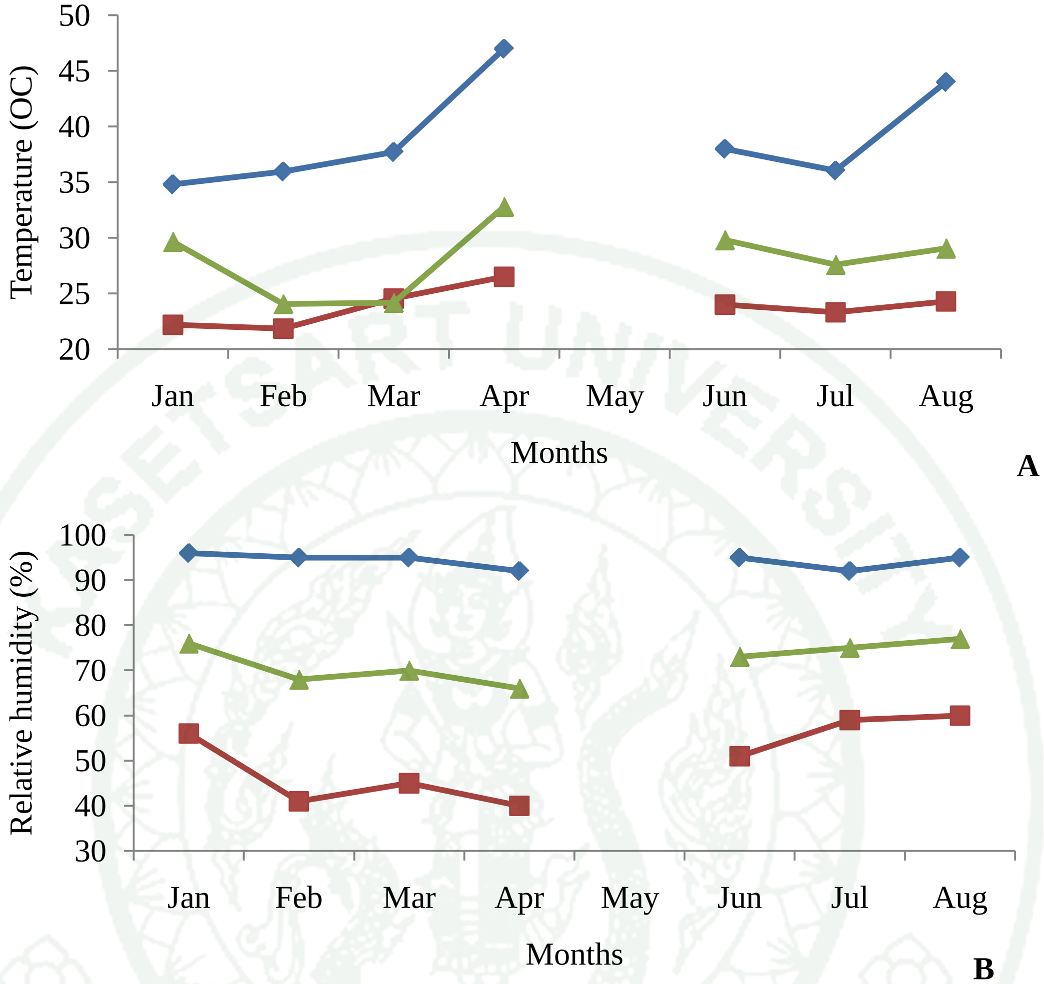
Appendix

Appendix Table A1 Mean number of *Frankliniella schultzei* (Trybom) per leaf caught in three lettuce cultivars of Iceberg, Red Salad Bowl and Read Rapid, grown hydroponically in a greenhouse

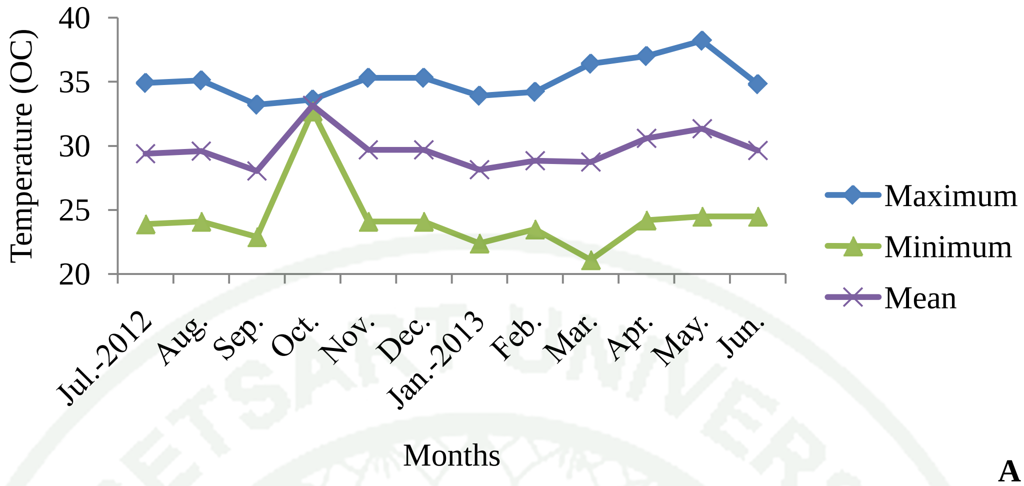
Month	Mean number of *F. schultzei*		
	Iceberg Lettuce	Red Salad Bowl	Red Rapid
January	0	0	0
February	2.05	0.35	0.41
March	107.97	90.00	76.3
April	0	0	0
May	-	-	-
June	2.40	0	0
July	2.87	2.05	2.40
August	3.35	1.90	0

Appendix Table 2 Mean numbers of *Chaetanaphothrips orchidii* (Moulton) per leaf caught in three cultivars of Green Oak, Red Oak and Butter Head grown hydroponically

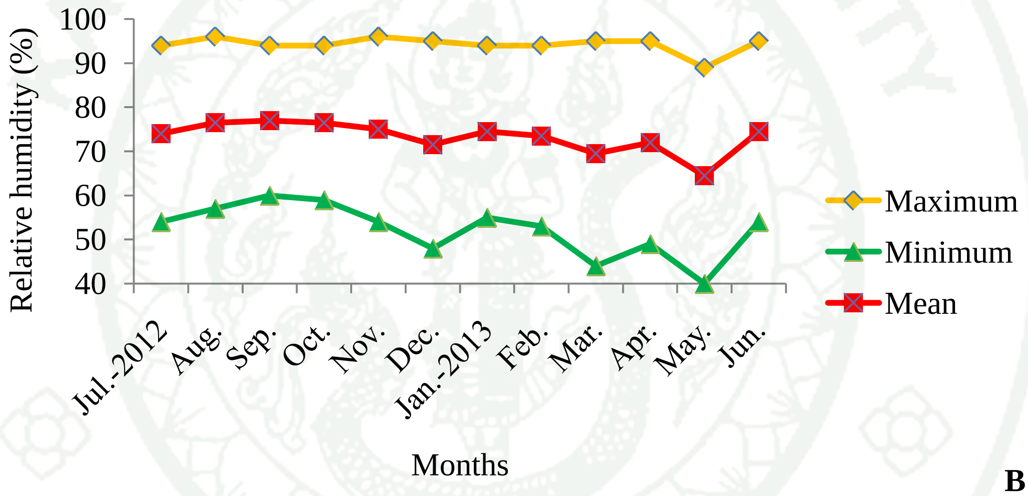
	Mean number of *C. orchidii*		
Months	Green Oak	Red Oak	Butter Head
July 2012	0.34	0.04	0.34
August	0.26	0	0.10
September	0.12	0	0
October	0	0	0
November	0	0.12	0.16
December	0	0	0
January 2013	0	0	0
February	2.90	0.56	0.34
March	1.88	0.16	0.44
April	4.26	0	0.90
May	12.00	0.40	4.94
June	0.40	0.08	0.40



Appendix Figure A1 Temperature (A) and relative humidity (B) data during studying period from January to August in 2012

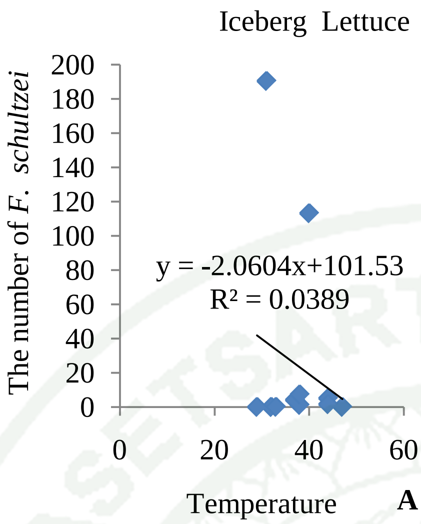


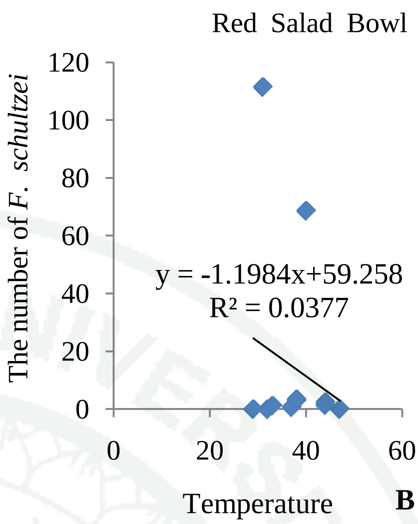
A



B

Appendix Figure A2 Temperature (A) and relative humidity (B) data during studying period from July 2012 to June in 2013





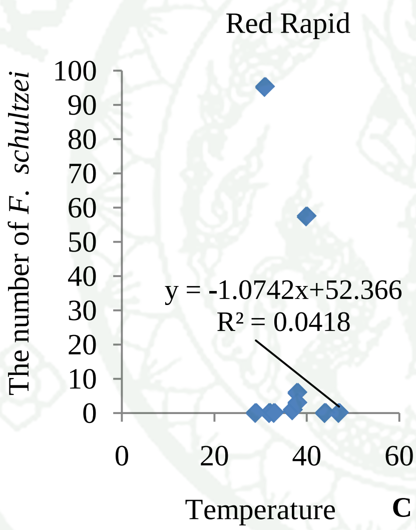
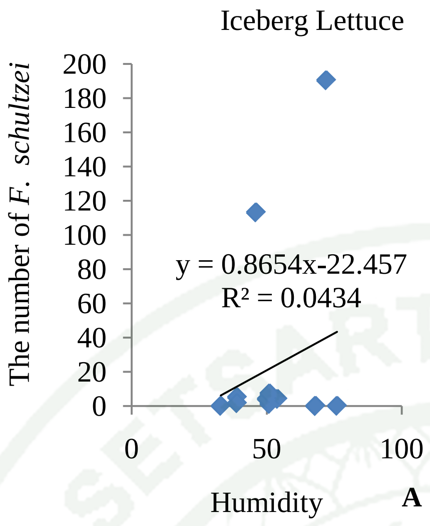


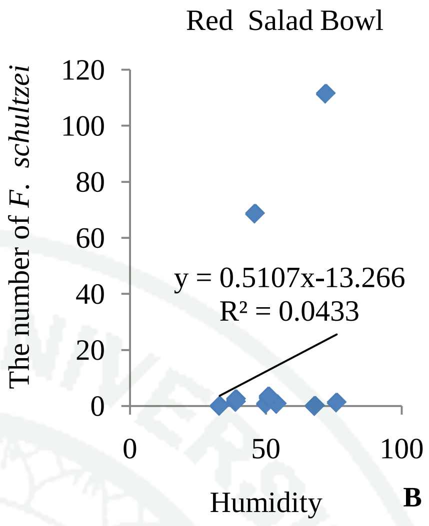
Figure A Relationship between population of thrips, and temperature in Iceberg Lettuce

Figure B Relationship between population of thrips, and temperature in Red Salad Bowl

Figure C Relationship between population of thrips, and temperature in Red Rapid

Appendix Figure A3 Relationship between the number of the common blossom thrips, *Frankliniella schultzei* (Trybom) (y) and temperature (x), The straight line regression equation of the number of thrips, *F. schultzei* is y = -2.060x+101.530 (A), -1.198x+ 59.258 (B) and -1.074x+52.366 (C) (Coefficient of regression = R^2 = 0.039 (A), 0.037 (B) and 0.042 (C), n = 100, P<0.05)





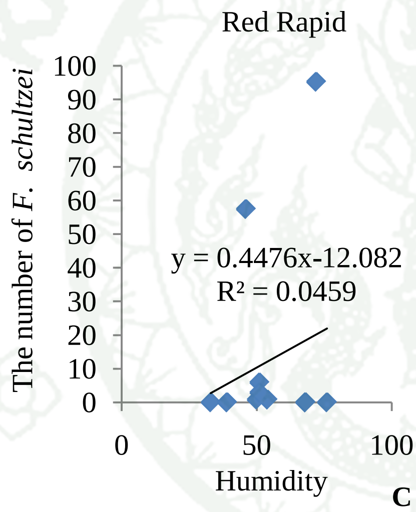
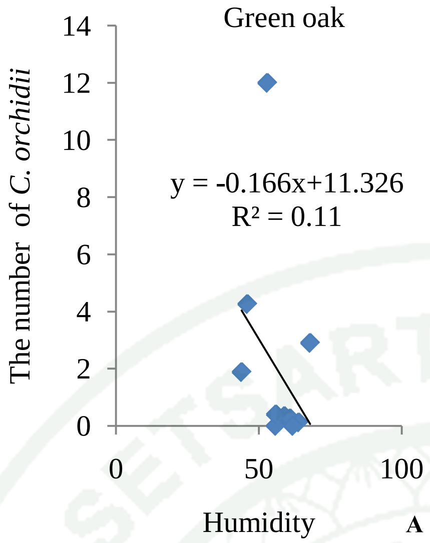


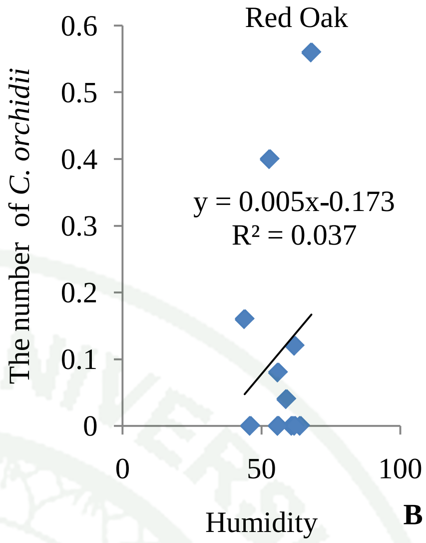
Figure A Relationship between population of thrips, and humidity in Iceberg Lettuce

Figure B Relationship between population of thrips, and humidity in Red Salad Bowl

Figure C Relationship between population of thrips, and humidity in Red Rapid

Appendix Figure A4 Relationship between the number of the common blossom thrips, *Frankliniella schultzei* (Trybom) (y) and humidity (x). The straight line regression equation of the number of thrips, *F. schultzei* is y = 0.865x-22.457 (A), 0.510x-13.266 (B) and 0.447x-12.082 (C) (Coefficient of regression = R^2 = 0.043 (A), 0.043 (B) and 0.0460 (C), n = 100, P<0.05)





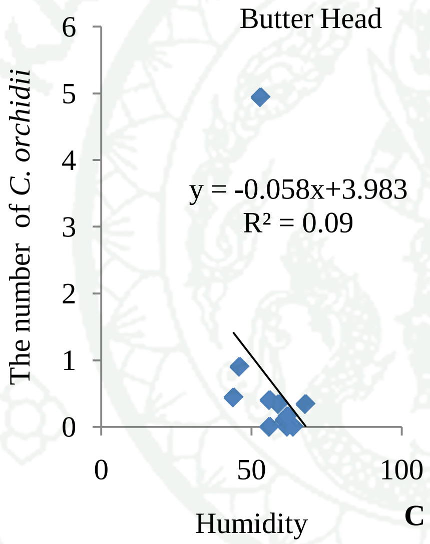


Figure A Relationship between population of thrips, and humidity in Green Oak

Figure B Relationship between population of thrips, and humidity in Red Oak

Figure C Relationship between population of thrips, and humidity in Butter Head

Appendix Figure A5 Relationship between the number of the anthurium thrips, *Chaetanaphothrips orchidii* (Moulton) (y) and humidity (x). The straight line regression equation of the number of thrips, *C. orchidii* is y = -0.166x+11.326 (A), 0.005x-0.173 (B) and -0.058x+3.983 (C) (Coefficient of regression = R^2 = 0.11 (A), 0.037 (B) and 0.09 (C), n = 50, $P<0.05$)

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