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Monitoring and pest control of Fruit flies in Thailand: new knowledge for integrated pest management.

by

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ABSTRACT

Fruit flies (Tephritidae) are serious pests that cause enormous losses for farmers in many countries. The frequent use of insecticides in controlling fruit flies in fruits and vegetable has not resulted in sustainable management of the pest. Problems associated with this complete reliance on chemical control are many residues of insecticides in crops, health problems for farmers, contamination of water and soil, insecticide resistance development and decrease in natural enemy populations. The implementation of control measures that do not imply an added burden to the environment and/or the farmers is urgent. More knowledge about the ecology of fruit flies is the basis for finding new and better ways to control this pest. This study aimed at 1) develop and testing of a modified Steiner trap constructed from used water bottles, 2) investigating the diurnal activity of adult males of *Bactrocera cucurbitae* and *Bactrocera dorsalis*, 3) monitoring for resistance to commonly used insecticides in *B. cucurbitae* and 4) conducting a survey among farmers with a focus on management of fruit flies. The research was carried out in Kamphaeng Saen, northwestern part Nakhon Pathom Province, Thailand from July to August 2009. We constructed an efficient trap from recycled bottles at the cost of 30 US cents (2.06 SEK) that can be used for monitoring and possibly also pest control. The results from the diurnal activity experiment suggest that *B. cucurbitae* and *B. dorsalis* are active in the morning. *B. dorsalis* showed an activity peak between 7 and 8 am. The activity for both species was low before noon and during the first hours of the afternoon. The bioassay gave no indications of development of resistance to the insecticides tested. Results from farmer surveys revealed that most of farmers have problems with fruit flies. The amount of insecticides used in the fields is great and the flora of the compounds is much diversified. We found also that the farmers spray their fields very frequently during a growing period until approximately one week before harvest and the spraying was carried out in a big degree during the cool hours of the day. The results also show that more than 50% of the farmers used protective equipment. I conclude that since the situation about the control of these pests is unsustainable the need for further and more intensive studies in this topic is urgent to carry out. But first of all is of priority to work together with farmers in the issue of the use of environmental friendly control methods to go away from the dependence of insecticides.

SAMMANFATTNING

Fruktflugor (Tephritidae) är allvarliga skadedjur som orsakar enorma förluster för jordbrukare i många länder. Den frekventa användningen av insekticider i kontrollen av fruktflugor i frukt och grönsaker har inte resulterat i en hållbar kontroll av dessa skadedjur. Problemen med detta totala beroende av kemisk bekämpning är rester av bekämpningsmedel i grödor, hälsoproblem för jordbrukarna, förorening av vatten och mark, insektsmedel resistens utveckling och minskning av naturliga fienders populationer. Genomförandet av kontrollåtgärder som inte innebär en extra belastning på miljön och jordbrukarna är brådskande. Mer kunskap om fruktflugornas ekologi är grunden till att hitta nya och bättre sätt att bekämpa de här skadegörarna. Denna studie syftar till att 1) utveckla och testa en modifierad Steiner fälla gjord av använda vatten flaskor, 2) undersökning av dygnsaktivitet hos vuxna *Bactrocera cucurbitae* och *Bactrocera dorsalis* hannar 3) testning för resistens mot vanliga insektsmedel i *B. cucurbitae* och 4) intervjua jordbrukare med fokus på bekämpning av fruktflugor. Studien utfördes i Kamphaeng Saen, nordvästra delen av Nakhon Pathom Province, Thailand från juli till augusti 2009. Vi byggde en flugfälla utav gamla vattenflaskor till ett pris av 2.06 SEK (30 US cents). Resultaten från dygnsaktivitets experiment antydde att *B. cucurbitae* och *B. dorsalis* var mycket aktiva på morgonen. *B. dorsalis* visade en aktivitets topp mellan klockan 7-8. Aktiviteten för båda arterna var låg på sen-förmiddagen och under de första timmarna på eftermiddagen. Testen gav inga indikationer i utveckling av resistens mot insekticider. Resultat från intervjuerna visade att de flesta jordbrukare har problem med fruktflugor. Mängden bekämpningsmedel som används av jordbrukaren är stor och den floran av föreningar är mycket diversifierad. Vi fann också att bönderna besprutar sina fält mycket ofta under en växtperiod och fortsätter till ungefär en vecka före skörd. Besprutningen utförs i stor utsträckning under de svala timmarna på dagen. Resultaten visar också att mer en 50% av jordbrukarna använder skyddsutrustning. Jag drar slutsatser att eftersom situationen om bekämpning av dessa skadegörare är ohållbart är det angeläget att ytterligare och mer intensiva studier i detta ämne görs. Men framförallt är det viktigt att prioritera att arbeta tillsammans med lantbrukaren i frågan om tillämpning av miljövänliga bekämpningsmetoder för att komma borta från beroendet av insekticider.

Contents

CHAPTER 1

1. Introduction

1.1. Background

The production of fruit and vegetables in Thailand generate important sources of income. These crops represent an important part of the gastronomic culture for Thai people. A constantly growing population, rising of incomes and urbanization levels increase the demand of fruit and vegetables. To fill the gap of this demand better farming strategies are necessary. The presences of pests such as fruit flies constitute an obstacle in their production. Fruit flies belonging to the family Tephritidae (Order: Diptera) are considered a very destructive group of insects that cause enormous economic losses in agriculture, especially in a wide variety of fruits, vegetables and flowers (Diamantidis, 2008). The total number of species within this family exceeds 4,000. Approximately 10% of them are serious pests distributed around the world in temperate, subtropical and tropical areas (Christenson and Foote, 1960; Weems et al., 1999; Singh, 2003). In particular, two species belonging to this family are of great importance in Thailand, namely Melon fly (*Bactrocera cucurbitae* (Coquillet)) and Oriental fruit fly (*Bactrocera dorsalis*). In cucumber (*Cucumis sativus L*) and bitter gourd (*Momordica charantia*) field infestation problems caused by *B. cucurbitae* are very common in Thailand (Ramadan and Messing 2003). The last named represents one of the most popular vegetables from the cucurbit family in this region. The cost of losses due to infestation of fruit flies can be surprisingly high, there are examples where losses have been up to 100% in cucurbit species, caused by Melon fly (*Bactrocera cucurbitae*) (Dhillon et al, 2005). Crop losses in mango (12-60%), guava (40-90%) and papaya (12-60%) have also been recorded by Allwood and Leblanc (1997). The damages on crops consist on oviposition stings on the fruit surface, fruit that drops early but also destruction of the inside of the fruits. This results in unmarketable crop.

The use of insecticides as the only way to control pests in fruit and vegetables causes environmental pollution and hygienic problems that represent a risk for people and animals (Gallo, 2007). In the last four decades the use of synthetic pesticides such as organophosphate and carbamates in an extensive way has led to the development of insecticide resistance in a number of pest species (Casida and Quistad, 1998; Claudianos et al., 1999; Hsu et al., 2004) and in Thailand residues of organophosphate and organochloride and other compounds have been detected in soil, water and crops (Thapinta and Hudak, 1998). In Thailand there are concerns about how to control fruit flies in the most efficient way. Insecticides in the form of pyrethroids, thriazopos have been used on cucurbits crops but the results have not been satisfactory. Resistance problems due to the overuse of such insecticides and high residues in the sprayed vegetables are some of the concerns that necessitate some form of management. Other approaches to pest fruit fly management, such as use of protein baits have been more or less ineffective because of our limited knowledge of the ecology of the fruit flies (Somta, 2009 Personal information).

Many ecological studies have been carried out on these two species (Jang, 1997; Kuba et al., 1982; Kuba et al., 1984; Smith, 1989). Despite this, a lot of knowledge is still lacking and it is indispensable to the understanding of these pests that this knowledge gap be filled. It is urgent to find more effective and environmental friendly control strategies that guarantee a sustainable production of fruits and vegetables.

1.2. Problem statement

Knowledge is needed that will increase the effectiveness (and safety) in the use of insecticides, and that gives farmers and pest advisors ideas about how to develop control schemes for this pest. A majority of studies carried out on Tephritidae are about the sexual and oviposition behaviour. Daily activity patterns have been studied less intensively and among the continents Asia has very few such studies (Aluja and Norrbom, 2000). Daily activity studies in fruit flies where behavioural factors like locomotion and feeding have been carried out (Miyatake, 1997) and some observations related to this topic are mentioned by Christenson and Fotte (1960). Diurnal activity of *B. dorsalis* and *B cucurbitae* under field conditions has not been investigated in Thailand. Since insecticide application is the main control strategy used by farmers it is crucial to know when during the day fruit flies are most active and therefore most likely to come into contact with the insecticides.

Furthermore, the construction of a trap for monitoring and control purposes by using material that can easily be acquired at a low cost will be useful for pest control but also for recycling. The major advantage of using traps is that the farmers have the possibility to monitor the species and number of fruit flies present in their fields. In addition the traps have the potential to be used as a primary tool in the control of fruit flies, then by using baited traps with insecticide and attractant. It is also important to develop an easy method to monitor insecticide resistance that can be used, for example, by local advisors and/or farmers without need to have complicated tools that often are difficult to obtain. Such a practical method could be used at least once a year.

Information from farmers regarding management of fruit flies but also insecticide use behaviour is indispensable to gather. That will give a better understanding about how serious the problem is and therefore how we should act. Related farmer surveys have been carried out by Lar Soe (2007) in Nakhon Pathom. However, it is important to collect additional information to fill empty spaces as regards the use of insecticides while setting differences between fields that grow chilli and cucurbit crops, two of the major important crops in this area.

1.3. Objectives

This work is aimed to 1) develop and test a modified Steiner trap constructed from recycled 1.5 l water bottles, and easily implemented by farmers, 2) record the diurnal activity of adult males of *B. cucurbitae* and *B. dorsalis* in two different fields located in the agriculture zone of Nakhon Pathom, Thailand, 3) carry out a quick bioassay to monitor resistance to two well-known insecticides and 4) interview farmers in this area with a focus on insecticide use and management of fruit flies. All studies were carried out in Kamphaeng Saen, Nakhon Pathom Province, Thailand from July to August 2009.

CHAPTER 2

2. Litterature review

2.1. Agriculture in Thailand

Thailand covers an area of 513 120 square kilometres; 180 259 square kilometres (35%) is arable land (NSO, 2004). The majority of Thailand´s population is engaged agriculture both directly and indirectly (Tualananda, 2000). Crops, forestry, fisheries, agriculture service and processing of agricultural products are the major divisions of the agro-sector. Favourable climatic conditions and its geographical position make the production of high quality tropical fruits possible in Thailand (Chomchalow et al., 2008). During economic crises like the one experienced during 1997 -1998, the agricultural sector has supported the national economy of Thailand significantly by serving as a source of employment for unemployed people from urban zones (Tualanda, 2000).

Farming activities can run throughout the year enabling the supply of fresh products in the market. The major crops grown are rice, maize, cassava, coconuts, sugarcane, soybean, rubber, and coffee. Fruits such as mango, lychee, longan, pineapple, and durian are important as are vegetables and ornamentals such as chilli, tomato, asparagus and flowers. Around 70 different kinds of vegetables are produced every year. Chili, with a production of 4 million tons in 1998 is a vegetable crop of major importance in Thailand (Nath et al., 1999).

2.2. Insecticides

The use of insecticides has changed agriculture worldwide. In Thailand the import of chemicals in 2003 was 4,6 million tons, a very remarkable increase compared with 1978´s level; 0.6 million tons. Insecticides, fungicides and herbicides are imported on a major scale into the country. The use of insecticides is remarkably high in vegetable and fruit plantations and its use has had a rising trend since 1977 (Figure 1). Consumer demand for uniform and perfect looking vegetables and fruits contribute to this increase. Organophosphate, organochlorine and carbamate compounds are the major classes of insecticides used in Thailand. The appearance of synthetic pyrethroids in Thailand occurred for first time in 1976 but proof of resistance development in e.g diamondback moth appeared very soon (Rushtapakornchai and Vattanatangum, 1986).

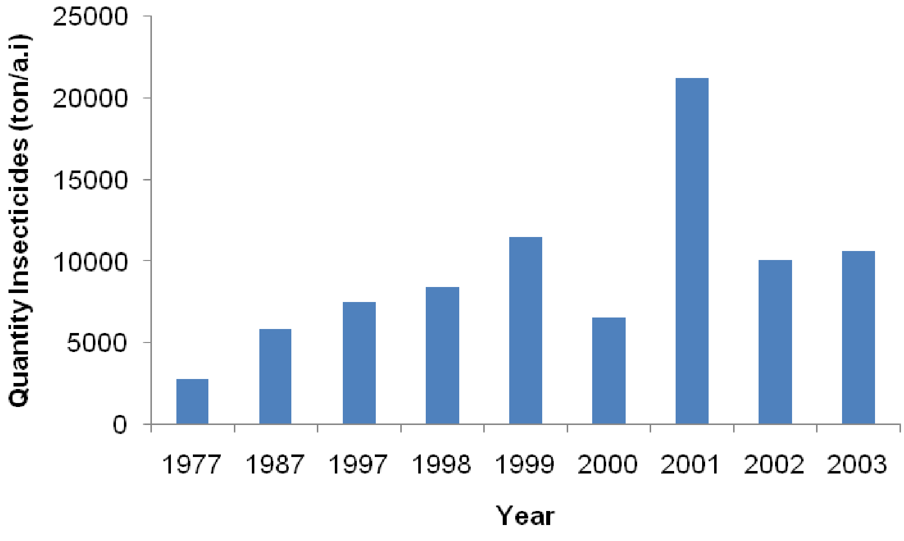


Figure 1. Amount (ton/a.i). of imported insecticides to Thailand. (Source: Department of Agriculture).

The application of insecticides is made directly to the crops; therefore traces of such compounds may remain even after harvest. This can be an obstacle for the exportation of the products. Although, many of the crops produced are sold through the informal market which means that small farmers take their products and sell them directly to consumers without any control of the hazard levels from insecticides. Cases of poisoning show how serious the problem is, but also traces of pesticides in soil and water revealed the dangerous results of the overuse of insecticides (Thapinta and Hudak, 1998). Studies on e.g. Malathion, a widely used insecticide in fruit and vegetables, showed of chromosome damage in animals and mammalian cells in cultures (Flessel, 1993). Also neuro-toxic effects are believed to be a result of a high level insecticide exposure (organophosphate, organochlorine and carbamate) as well as increased risk of Parkinson disease (Alavanja et.al., 2004; Kamel and Hoppin, 2004).

Most of the pesticides used in Thailand are imported. The percent of pesticides used in fruit and vegetables were in 1995 nearly ¼ of the total use of chemicals compounds (Figure 2). A quite new insecticide is Fipronil, which is a very toxic insecticide for animals and possible carcinogen for humans (Kegley, et al., 2009)

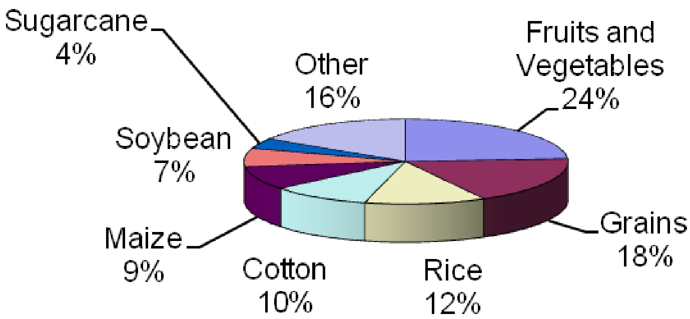


Figure 2. Pesticide use in Thailand. (Source: OAE, 1995)

2.2.1. Resistance development

Insecticide resistance is a serious problem in agriculture, ending up with the tolerance and /or adaptation of insects to insecticides. The selection pressure that the insecticides place on the insects makes the organisms with a high fitness to develop resistance. The factors that influence the development of resistance are: speed of reproduction, mutation and migration of the insects but also persistence and specificity of insecticides, frequency and number of applications and type of use insecticide (Aldridge 2009).

Choice of compounds has been more or less based on economic factors (cheap and effective products that ensure best possible control) rather than the negative effects that the use of pesticides can have. The impact of different insecticides on both humans and the environment can vary a lot, therefore a list over insecticides used in agriculture is assigned with a value (environmental quotient) that represent the influence on farm workers and environment has been produced by Kovach, et al., (2009) (Table 1). The first category represented are the farm workers, which is based on the time of exposure to insecticides, the effect on consumers and leaching, two components that have been put together due to the effect on human health by for example contamination of groundwater and ecological component, which refers to the chemicals effects on fish, bees, birds, and beneficial arthropods. The insecticides presented in the table are some of the most commonly used in Thailand. The main purpose with the values assigned to each insecticide is to guide farmers and other people that work in agriculture, but also consumers, about the impact of pesticides (Kovach, et al., 2009). The significant impact that insecticides cause on natural enemies is often underestimated but also the influence on organisms that contribute to e.g. soil´s fertility depend on what kind of compounds are used (Gallo, 2007).

Table 1. Environmental quotient of insecticides. The lower the value the lower the impact on health and environment. (Source: Kovach, et al., 2009)

Insecticide	Trade name	Farm worker	Consumers + leaching	Ecology	Farm work + consumer + ecological /3
Abamectin	Agri-mek	13.8	3.9	86.4	34.7
Acetamiprid	Assail	6.9	7.4	72.0	28.7
Carbosulfan	Posse	6.9	8.4	126.7	47.3
Cypermethrin	Cymbush	13.8	4.9	89.4	36.4
Dichlorvos	Vapona	41.4	17.6	100.8	53.3
Emamectin benzoate	Proclaim	9.0	4.0	65.0	26.3
Fipronil	Regent	60.0	9.0	203.8	90.9
Malathion	Cythion	9.0	4.5	58.0	23.8
Rotenone	Fertilome	6.9	2.1	78.3	29.4
Triazophos	Hostathion	62.1	7.4	37.3	35.6

2.3. Trapping

Trapping is a useful tool that offers a lot of possibilities to the study and control of fruit flies. The species presented in a determined area can easily be catalogued by determining their geographic situation, seasonal abundance, host status and monitoring of already established fruit fly populations (Allwood, 1997). The information collected in traps such as number of flies and species, is a valuable source for the planning of control programs but also for quarantine detection. The attractants and lures can be of either synthetic or natural origin and are used to catch the male insects. The attractants are several; methyl eugenol, cuelure and trimedlure are the most commonly used. To trap females, food baits based on fermented sugar are used. Methyl eugenol was used already in early 1900 (Howlett, 1912) and its effectiveness in attracting e.g. *B. dorsalis* has been well proven. There is evidence that methyl eugenol is involved in the mating effectiveness where males that feed on this lure increase mating success (Shelly and Dewire, 1994). Similar results were found in studies performed on males that feed on cuelure and trimedlure. However, the results are not as clear as for methyl eugenol (Shelly et al. 1996; Shelly and Villalobos 1995). Cuelure is widely used to catch *B. cucurbitae* and *B. tryoni* but studies demonstrated that it can attract to more than 150 different species of the genus *Bactrocera* (IAEA, 2003). Trimedlure has been show to be very effective attracting *Ceratitis capitata* and *Ceratitis rosa*. Methyl eugenol can attract nearly 100 different species of the genus *Bactrocera* (IAEA, 2003). The response to lures is low during periods when adults are sexually inactive as in winter but also age and time of day can be influencing factors.

2.4. Traps

The devices used to trap fruit flies are several but the most commonly used are the McPhail trap, Jackson trap, and Steiner trap. The McPhail trap is commonly used with protein baits. A common combination between kind of trap and attractants that has remained due its efficiency is the use of Steiner traps baited with Methyl eugenol and cuelure, Jackson traps baited with trimedlure and McPhail traps baited with a protein attractant (IAEA, 2003).

The Steiner trap consists of a plastic cylinder with an opening at each end, to minimize the risk of escape wire gouze covers half of the entrances. Through these openings the flies will go inside and feed on the lure. The trap has a hanger to hang the trap out in the field. Inside, a support to suspend the attractant piece is placed in the middle of the cylinder (Figure 3).

Figure 3. Steiner trap.

Jackson traps is a delta shaped trap made of material that stands the fields conditions (e.g. waxed cardboard material). Inside the trap there is a hanger to suspend the lure and in the base a layer of some sticky material cover it, that to retain the catches. On the top of the trap there is a wire hanger which serves to hang the trap out in the field. The need of extensive maintenance may be one disadvantage.

McPhail trap is appropriate for monitoring and mass trapping of flies due to the generous volume of the container and it is used to catch both females and males. The flies go inside the trap through openings located on the bottom of the trap. Attracted by protein baits the flies drown in a liquid baited with insecticide. On the top of the trap there is a hanger to hang the trap from tree branches.

2.5. Fruit flies - biology and life cycle

Fruit flies breed in fruits but also in other living plant tissues as leaves, buds, stems and flowers. The host ranges of fruit flies can vary from monophagous (e.g. Mediterranean fruit flies) to highly polyphagous (e.g. Melon flies and Oriental fruit flies). Simplified it can be said that fruit flies go through four development stages; eggs, larvae (three larval instars), pupae and adults. The life cycle from egg to adult takes between 14 and 27 days. The duration of each stage and degree of survival depends on species, host plant and environmental conditions (Shaw et al., 1967) (Table 2). Adult fruit flies have a diet based on secretion of plants from leaves, fruits and rotting fruits but also nectar, pollen, bird feces, and honeydew secreted by other insects (Christenson and Foote, 1960). Protein obtained from for example honeydew helps fruit flies to reach a normal fertility and stimulates egg production. Studies on fruit fly mating behaviour revealed that most of flies in tropical and subtropical areas mate when light intensity decreases at dusk (Bateman, 1979). Although some species belonging to the genus *Bactrocera* prefer to mate in the morning and early afternoon (Alwood, 1997). Oviposition occurs in stings made by other fruit flies or other injures in the skin. Fruit flies can move long distances within a short time (Bateman, 1979). Exceptional observations made by Miyahara and Kawai (1979) showed than a species of the genus *Bactrocera* could move up to 200 km. During the larvae stage fruit flies can move long distances by jumping, these movements seem to be in random directions (Christenson and Foote, 1960) and are probably defence behaviour against insect predators (Fletcher, 1987).

Table 2. Biology review of two important fruit flies belonging to genus *Bactrocera*.

Specie	**Host**	**Duration of development stages (days)**				
		Egg	**Larvae**	**Pupae**	**Adult**	**Number of eggs**
B.cucurbitae (Melon fly)	Cucumber, water melon, squash, tomato, beans, peppers, cowpea and more than 125 fruit, vegetables and some wild plants. Temporary host plants occur e.g. papaya, orange, mango and peach.	Under field conditions eggs hatch after 26 to 28 hours.	Between 4 to 9 days. Variations occur depending of kind of fruit and environmental conditions.	Pupal stage can vary between 7 to 11 days. Temperature is a very important factor.	Normally an adult fly will live between 1 to 3 months. There is prove of 462 days of life span.	During life time 1000 eggs a single female can lay.
B. dorsalis (Oriental fruit fly)	Guava, mango, papaya, avocado and more than 200 fruit and vegetables.	24 hours under summer conditions; 20 days in winter.	9 to 35 days; 6 to 7 under optimal environment.	10 to 26 days depending of temperature. Longer period under cool temperature.	One to three months. About one year under cool conditions.	1200 to 1500 eggs per female. The size of the fruits can influence the number of eggs per fruit - small fruits fewer eggs.

After Christenson and Foote (1960).

2.4.1 Damage

Fruit flies damage fruits by puncturing and laying eggs under the soft skin in both mature and green fruits (Hollingsworth and Allwood, 2000). The eggs hatch and feed inside the fruit causing the fruits to rot (Dhillon, 2005) resulting in unmarketable fruits. Due to the larva's three instars the fruits can be totally destroyed (Ye and Liu, 2005). Furthermore, injuries caused by the larvae may be used as gateways by secondary organisms (e.g. bacteria and fungi) and contribute to further destruction of the fruit. At maturity, larvae emerge from the damaged fruit and drop to the ground and pupate in a burrow (4-8 cm) prepared by the pre-pupa. Infested fruits often drop to the ground prematurely.

2.6. Management of fruit flies

Fruit fly management can be divided in 4 different categories: chemical, cultural, biological and genetic.

2.6.1. Chemical control

Chemical control is widely used among farmers. The first synthetic chemical insecticide used to control fruit flies was DDT. Eventually, DDT was replaced by organophosphates. The application of insecticides is done by spray cover on the entire crop or trees. Insecticides can also be used in a mix with attractants like cuelure and methyl eugenol. This is a technique called Male Annihilation Technique (MAT) and consists of many bait stations throughout the field. The mixture (attractant and insecticide) can be applied in traps like Steiner traps but also in e.g coconut husk block and soaked paper. This method reduces the male proportion in a population to a low level and therefore mating does not occur. Experience in field demonstrated that the level of infestation in mango in India decrease to 5% from levels of infestation between 17% and 66% by using this technique (Verghese et al, 2006).

Insecticides can even be used together with protein baits. This method is very important in the control of both female and male fruit flies in distinction when using insecticide and attractants who is specified for male fruit flies. The protein baits consist of hydrolysed protein mixed with an appropriate insecticide and applied on crop canopy in different places in the field (spot technique) (Allwood et al., 2001).

2.6.2. Cultural control

Among the techniques that have shown good results the following are the most successful sanitation measures, growing crops that better can withstand fruit flies attacks, early harvest, and bagging.

Sanitation measures
The infested fruits should be removed; in particular the fruit on the tree that present signs of attack should be removed instead of removing fallen fruits on the ground were the larvae have already left the fruit. In fields where sanitation measures are practice the level of fruit flies decreases significantly (Verghese et al., 2004).

Resistant crops
The production of crop varieties that are less attractive for fruit flies has shown good effects. There are some chilli varieties that are classified as non-hosts for fruit flies in Fiji Islands. In Thailand there are some fruit crops that are not susceptible to fruit fly attacks (Allwood et al., 2001).

Early harvest
Fruit flies prefer to attack fruits and vegetables depending on the stage of maturity. In some crops there is the possibility to harvest fruits early to avoid fruit fly infesting.

Bagging
This is a kind of exclusion. A single fruit or a cluster or even a whole tree can be covered by a bag. The bags prevent fruit flies from infesting the fruits. Often the bag is made of paper but also cloth can be a material resistant enough. Bags made of old newspaper can be an economic and effective way to protect the fruits. In Thailand this method is used in particular in mango orchards (Allwood et al., 2001). Even plant leaves can be an appropriate material for bagging fruits (e.g. banana).

2.6.3. Biological control

Introduction of parasitoids to infested fields has given good results in management of fruit flies. The use of biological control to control fruit flies started already in 1902 (Wharton, 1989). There are examples where reductions of infestation have been nearly 95% as the experiment in Hawaii showed when larve parasitoids belonging to the families Eulophidae, Braconidae and Chalcididae were introduced (Allwood et al., 2001). *Psyttalia fletcheri* (Hymenoptera: Braconidae) is one of the parasitoids that had showed a high parasitism degree in *B. cucurbitae*, *Fopius arisanus* (Sonan) is other promising parasitoid tested in Hawai to control *B. latifrons* (Bokonon-Gatan et al., 2007). A biological control can also be conducted via measures that favour the established parasitoids in a kind of conservation of biological control agents. The biocontrol agents are often reared in different localizations than the place where they will be released. In Thailand, it is reported that the potential to find Eulophidae parasitoids that can be used in Hawaii is great, especially in the north region (Ramadan and Messing, 2003).

Apart from regular parasitoids even birds that feed on infested fruits in the field are very important for the reduction of fruit fly populations. Sometimes that kind of predation has been more successful than the control of fruit flies by parasitoids.

2.6.4. Genetic control

The Sterile Insect Technique (STI) is based on the release of sterilised male fruit flies into the field. Competition between sterile and wild males for females will end up with females mating with sterile male flies and therefore no offspring will be generated. Radiation is used to sterilize the flies. This method requires a great amount of sterile flies which should be in same proportions to the number of the wild flies but also an appropriate rearing of flies that carry many of the genetic characteristics presented in the population that will be controlled (Itô et al., 2003).

2.7. Asian Regional Center

This study was done at the request of AVRDC –The World Vegetable Center. It is an international agricultural research center dedicated to vegetable research and development. The headquarters is located in Taiwan and they have a large number of regional offices in different parts of the world. The main purpose of this center is to alleviate poverty and malnutrition in the developing world through the increased production and consumption of safe vegetables (AVRDC brochure, 2009). This study was carried out at the research station of Asia Regional Center, located in Kamphaeng Saen, under the supervision of its director Dr. Peter A. C. Ooi.

CHAPTER 3

3. Material and Methods

3.1. Experimental sites

The study was carried out in Thailand in two farmer production areas around Kamphaeng Saen district (Figure 4), in Nakhon Pathom Province, located 90 kilometres west of Bangkok. Nakhon Pathom is a province located northeast of Bangkok. It is neighboured by Suphan Buri to the north, Nonthaburi to the east, Kanchanburi to the west, Ratchaburi to the south west and to the south Samut Sakhon. The province is divided into 6 districts; Kamphaeng Saen, Muang Nakhon Pathom, Nakhon Chaisi, Sam Phram, Bang Len and Don Tum The agriculture in this zone has a great diversity but fruit and vegetables occupy a main place. The majority of fruit and vegetables produced in this zone are distributed in the local market and a lesser part is exported (Lar Soe, 2007). According to Phadungchom (1999), in this province, pesticides use is around 19-24% of the total costs of the production of vegetables. The other costs are labour, fertilizer and seeds.

The fields studied were located 540 metres from each other. The coordinates for field one and field two are, N 13° 56.278’ E 099° 58.245’ and N 13° 55.910’ E 099° 58.577’, respectively.

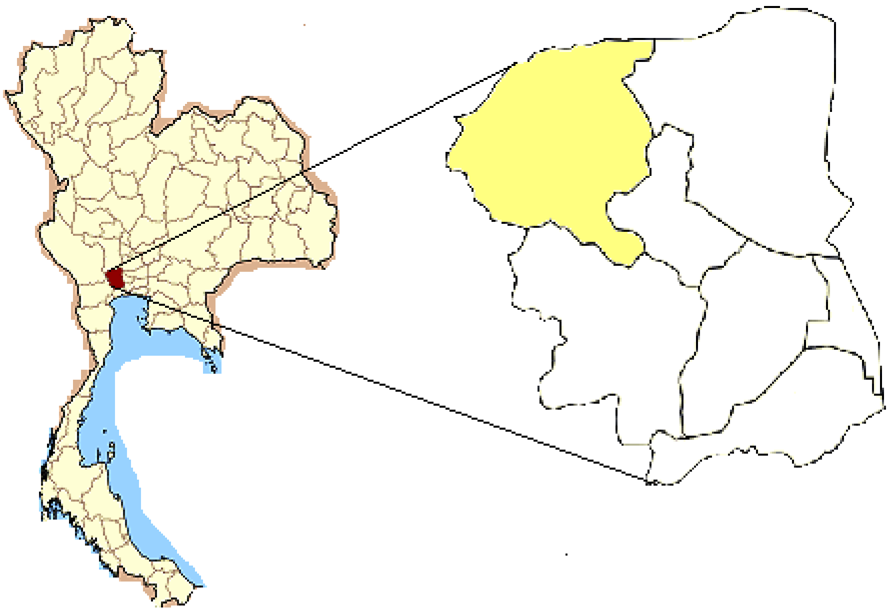


Figure 4. Map of Thailand (left) and Nakhon Pathom province (right). Kamphaeng Saen district is highlighted in yellow.

The vegetation compositions in the fields studied were similar, a mix of tree fruits and annual vegetables.

Field 1
- Mango
- Guava
- Star fruit
- Papaya
- Chili
- Sugar cane
- Citron grass
- Acacia trees

Field 2
- Rose apple
- Cucumber
- Papaya
- Banana
- Ivy gourd
- Beans
- Mango
- Surinam cherry

3.2. Construction of traps

Traps were constructed based on the Steiner traps principle using used water bottles (1.5 l). The tops of the bottles were cut and later inverted into the body. The edge was sealed with transparent tape. A perforation of the size of a coin (diameter 20 mm) was made in the bottom of the bottle. A holder for the attractant was placed inside in the middle of the trap body and yarn to hang the traps in the field was attached on the top side of the trap (Picture 5). The attractant pieces inside the trap, consisted of a piece of cloth (3 x 2 cm) soaked with 1 ml of attractant (cue-lure or methyl eugenol). The trap had two openings covered with a piece of plastic mesh. The plastic mesh was fastened using glue leaving half of the entries open (Picture 6). Glue was also used to cover and strengthen the holder and the support (metal hook). A detailed list of the material used in the construction of the traps is presented in Table 3.

Table 3.Material used for the construction of a modified Steiner trap.

Product	Description
1.5 l Water bottles	1 bottle/trap
Yarn	20 cm length
Metal hook	
Glue	-
Tape (transparent)	-
Plastic mesh	The size of a coin

Figure 5. Construction of fly traps by recycling used water bottles.

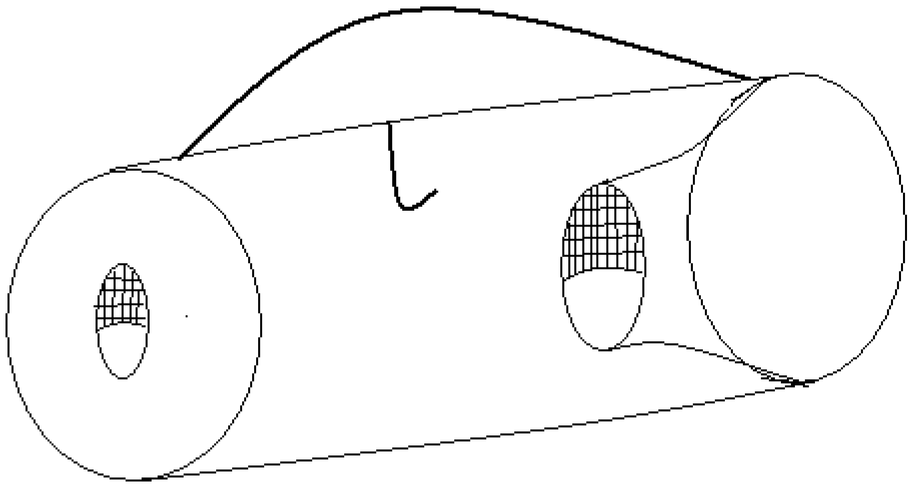


Figure 6. Model of a modified Steiner trap, constructed by using used water bottles.

3.3. Diurnal study of fruit flies

Traps were baited with two kinds of attractants, namely methyl eugenol (4-allyl-1,2-dimethoxybenzene-carboxylate) and cue-lure [4-(p-acetoxyphenyl)-2-butanone]. Both attract males of *B. dorsalis* and *B. cucurbitae*, respectively (Vargas et al., 2000). In the field, the traps were hung from trees close to the field and about 1m above the ground.

The traps were placed in two different fields twice a week to record the activity of fruit flies. The experiment was carried out during two weeks for each attractant. One trap at a time was hung and changed after every 60 minutes, in total 8 traps were used during one sampling opportunity (Figure 7). The experiment started at 6.00 am and lasted until 14.00 pm.

Figure 7. Traps made from used water bottles.

The temperature in Nakhon Prathom during the time of the study were on average 24.2 and 24.4 in July and August, respectively (Appendix A)

3.4. Fly identification

All the fly individuals were counted and identified in the laboratory of AVRDC-ARC by using a pictorial guide[1] from the International Centre for Management of Pest Fruit Flies (ICMPFF). A second opinion for the identification was given by Dr. Amporn Winotai, entomologist at Plant Protection Research and Development Office, Department of Agriculture, Thailand.

3.5. Insecticide bioassay

Traps were hung in the same fields where the diurnal activity experiment was carried out. The traps were hung in the afternoon and collected next day in the morning. A total of ten traps were used each time when the collection was carried out. This activity was repeated 4 times. The materials in this experiment were empty water bottles, pieces of cloth, rubber bands and bottle caps. The treatments were: no food, only sugar, abamectin, fipronil, abamectin + sugar and fipronil + sugar (Table 3). The insecticide dose used in this experiment is the highest dose recommended on the label of the products, namely abamectin 40 ml/20 l water and fipronil 20 ml/20 l water.

In the lab the flies were transferred to different water bottles previously cut at the bottom and the opening closed with a cap (Figure 8). Ten flies were placed in each bottle for each treatment. The flies were transferred by using a black blanket around the trap, which is a technique that makes the flies fly from the dark place (inside the trap) into the light place.The treatment (Table 4) was put in a bottle cap with a piece of cotton and placed carefully inside the bottle. The mortality of the flies was observed after 3, 6, 18, 24, 48 and 72 hours.

Table 4. Treatments used in insecticide bioassay to monitor resistance in *B. cucurbitae.*

Treatment	**Composition**
No food	-
Only sugar	1 ml 5% sugar solution
Abamectin	1 ml Abamectin (2µl abamectin + water)
Fipronil	1 ml Fipronil (1 µl Fipronil + water)
Abamectin + sugar	1 ml Abamectin + 1 ml 5 % sugar solution
Fipronil + sugar	1 ml Fipronil + 1 ml 5 % sugar solution

The experiment was carried out under approximately 22°C and a period of light of 12 hours.

[1] Pictorial Key to Common Southeast Asian Fruit Flies (Diptera: Tephritidae: Dacinae) prepared by the International Centre for Management of Pest Fruit Flies, Kuala Lumpur, Malaysia

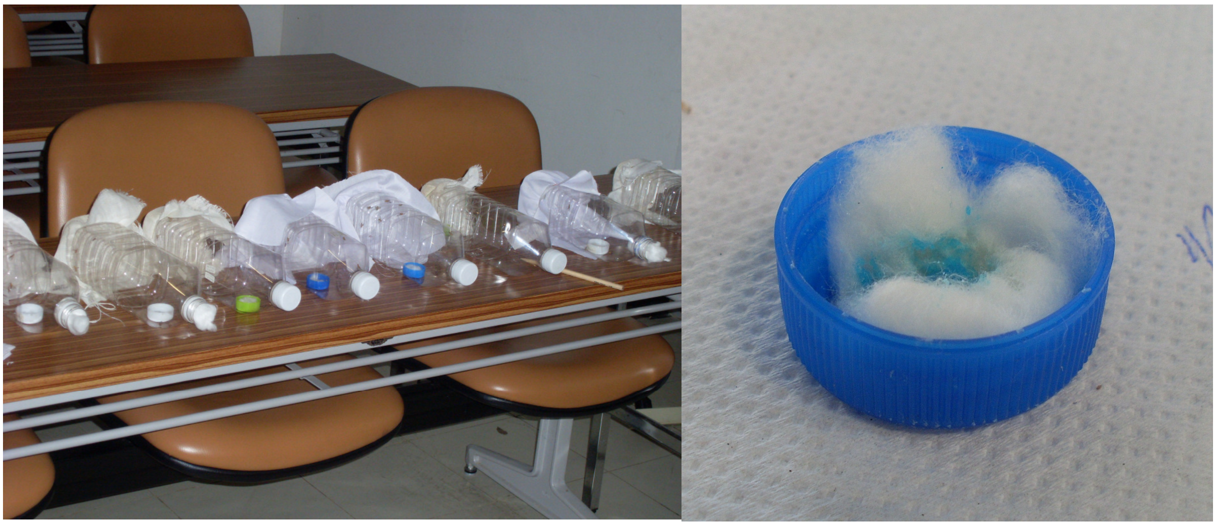


Figure 8. Arrangement of the insecticide bioassay (left) and a cap prepared with one treatment for the same bioassay (right).

3.6. Farmers survey

In order to understand the fruit fly management by farmers in Kampaeng Saen district, one of the six districts of Nakhon Pathom, interviews were carried out. In total 20 farmers were interviewed, 10 chili producing farmers and 10 cucurbit growing farmers. Both men and women participated equally in the interviews. All the farmers were selected randomly. Each interview took an average of one hour and the questionnaires consisted of 18 questions related to fruit fly management (Appendix B).

No appointment was needed for the interviews and in order to obtain reliable results with reliable data, farmers were interviewed in their houses or their fields. The idea was to have the farmers in an environment where they do not feel strange.

3.7. Data analyses

A Repeated Measures Analyses of Variance was used to analyse the data from the insecticide bioassay. This statistical analysis is suitable when working with the same materials all the time, which we did in the insecticide bioassay. The analysis of the data obtained from the diurnal activity experiment was done by using Standard ANOVA, where comparisons of the different treatments were done using Student-Newman-Keuls test (SNK) (SAS Institute, 2009).

3.8. Study period

The study was carried out during a period of two months (July – August, 2009) under an internship arrangement between the Swedish University of Agricultural Sciences and the Asian Regional Center, AVRDC-The World Vegetable Center. The study was partly funded by the Swedish International Development Cooperation Agency. The duration was a limiting factor in this study.

CHAPTER 4

4. Results

4.1. Construction of modified Steiner traps

The construction of one trap utilizing used water bottles took between 5-10 minutes. All the bottles were carefully washed before use to avoid contamination risk. The material used was purchased from different places in Kamphaeng Saen district. The total number of constructed traps was considerably more than one hundred. An approximation of price for the construction of one single trap is 30 US cents (2,06SEK).

4.1.1. Testing of the traps

The traps were tested during the experiment intended to record the diurnal activity of fruit flies but also during the gathering of fruit flies needed to carry out the test to detect insecticide resistance (See 4.2 & 4.3). The two different attractants were used under different periods. The study started with cue-lure and lasted the whole month of July, 2009. Methyl eugenol, was used the following month. The traps were prepared one day in advance and stored at room temperature until it was time to use them.

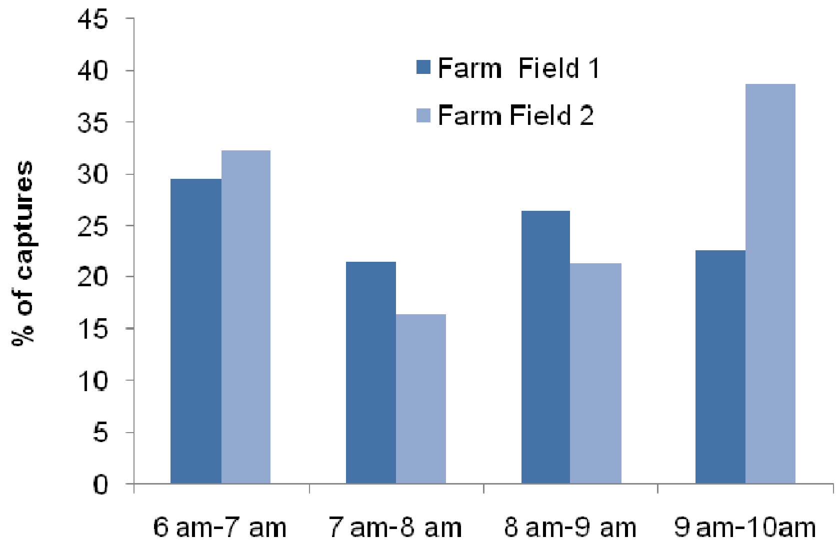
The total number of fruit fly captured during the two months of this study in Kampaeng Saen was 695 for *B. cucurbitae* and 761 for *B. dorsalis*. Furthermore, other species were found namely *B. correcta*, *B. caudata*, *B. apicalis* and *B. cilifera* (Table 5).

Table 5. Number of fruit flies catches during July and August, 2009 in KPS.

	Fruit Fly species					
	B . dorsalis	***B. cucurbitae***	***B. apicalis***	***B. caudata***	***B. cilifera***	***B. correcta***
Number of collected flies	761	695	12	65	47	59

4.2. Diurnal experiment

During the first month of this work the Melon fly was studied. In a period of two weeks, four observations were performed. The two first observations (21 and 23 July) were carried out from 6 am until 10 am (Figure 10). For the two other observations (29 and 31 July) the time of collection was from 6until 2 pm (Figure 10). During the two first days of observation a majority of flies were caught between 6 and 7 am in field 1 (30%) and between 9 and 10 am in field 2 (39%). Differences between numbers of catches between the fields were observed, the major variation was registered 9 am.
The two other observations for the same species (Figure 9, below) shows the major percent of catches between 7 and 8 am (33%) in field 2 and two hours later in field 1 (30%). The activity decreases with time in both fields and differences in catches were observed between both fields. The greatest difference was observed at 7 am.



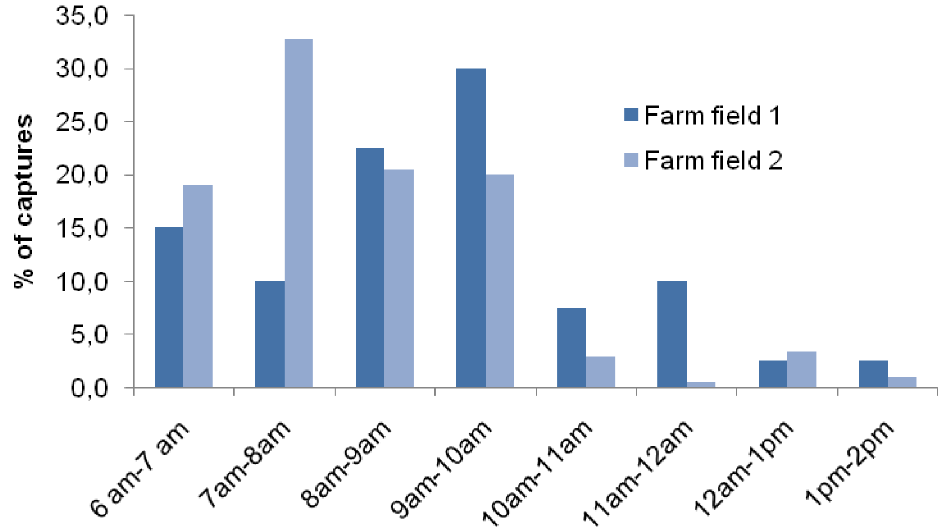


Figure 10. Percent of *B. cucurbitae* attracted by cue-lure in Kamphaeng Saen, Thailand in July 2009. A total of four observations were carried out. The length of the experiment differs between the observations. Figure 10A (upper) shows catches from two days of observation during a time of four hours each. Figure 10B (down) shows percentage of catches from two days observation during a period of study of eight hours.

The data obtained from four collection times carried out in August 2009 for Oriental fruit fly showed that the major percent of flies were collected between 7 am and 8 am (35% in both fields). Also during the first hour of monitoring (6-7 am) a high percentage was registered (20% and 17% for field 1 and field 2, respectively). A lesser variation in the number of catches between both fields was obtained and the activity followed a pattern where the number of catches decreases with time (Figure 11).

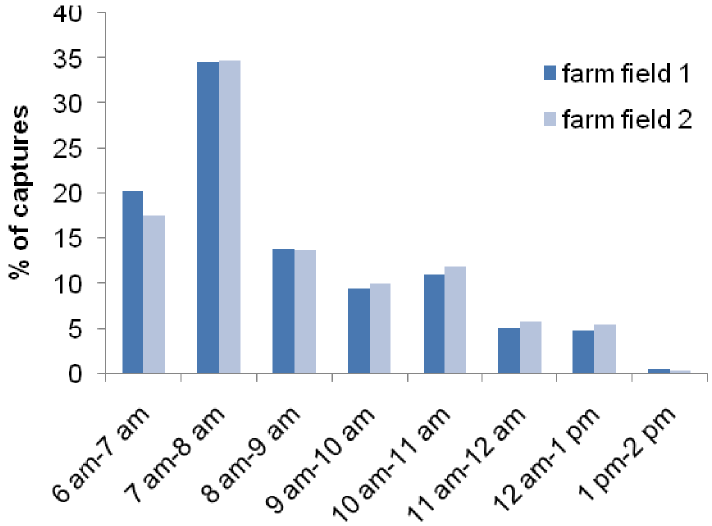


Figure 11. Procent of *B. dorsalis* attracted by methyl eugenol in Kamphaeng Saen, Thailand in August 2009.

4.3. Bioassay

The flies were exposed to six different treatments. In the treatments with a mixture of insecticide and sugar noticeable mortality was observed after 6 hours of exposure. Total mortality was observed for flies treated with Abamectin and sugar after 48 hours and for Fipronil and sugar 70 hours after of exposure. In the group treated with only a sugar solution the survival observed was high during the three days of observation, although a decreasing pattern was noted (Figure 12A). Flies treated with only insecticide showed a total mortality similar to the flies that did not receive any sugar solution. For the flies treated with only insecticides total mortality was noted after 50 hours of exposure, although for Fipronil exposure flies total mortality was noted already after 24 hours (Figure 12B).

A statistical analysis showed significant difference ($P<0.0001$) between the different treatments and time. There was no significant difference among the dates when bioassays were performed ($P=0.11$). Studies of flies from two different fields were not significantly different ($P=0.07$). Using the Student-Newman-Keuls test it was seen that after 3 hours treatments containing abamectin had significantly higher mortality than all the other treatments. After 6 hours the treatment where sugar water was provided had significantly lower mortality than all the other treatments. Abamectin treatments still had the highest mortality and were significantly different from the control and fipronil treatments. By 18 hours after the start of the experiment the sugar treatment had significantly lower mortality than all other treatments and there was no difference in mortality among the other treatments. This pattern continued until the end of the experiment at 72 hours.

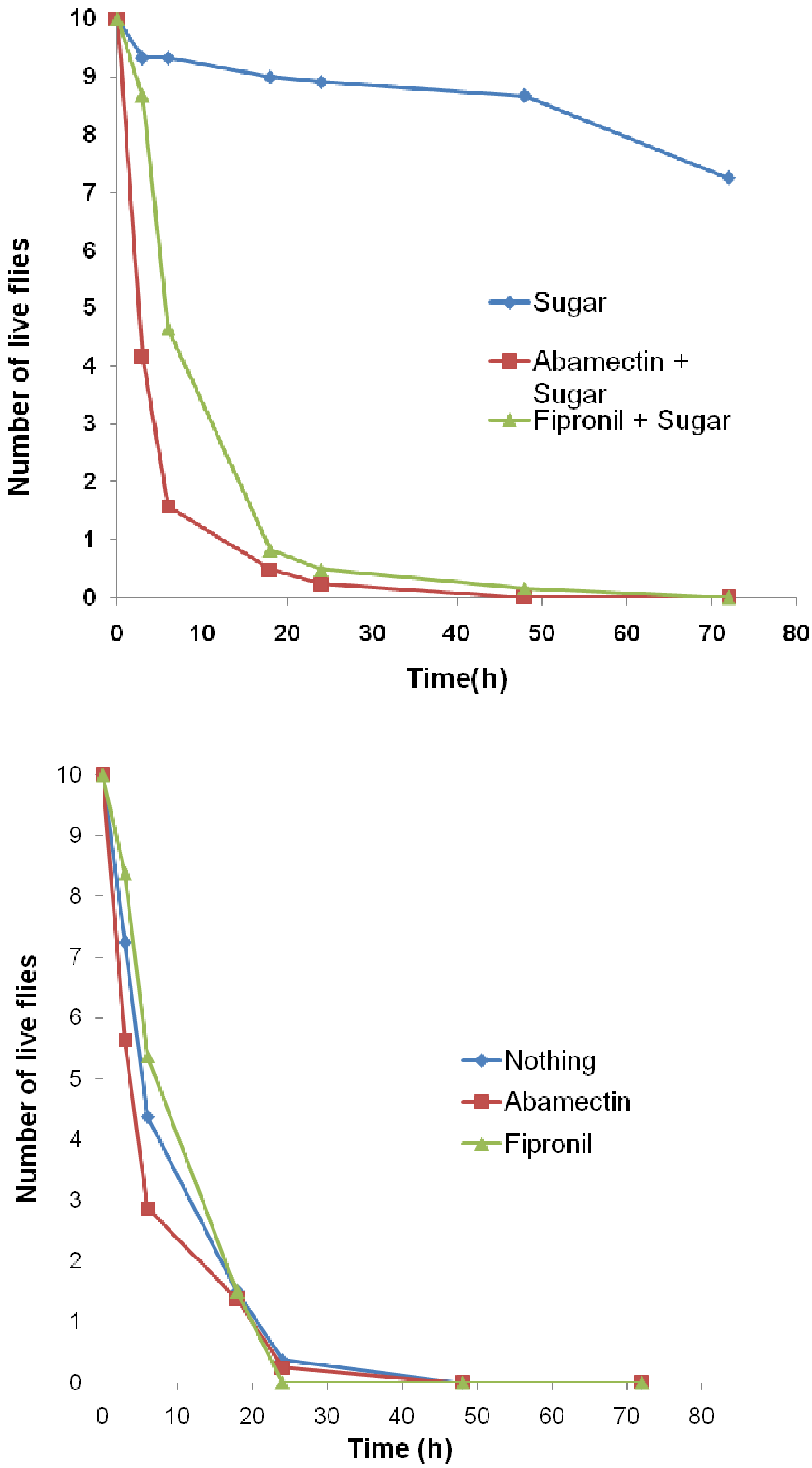


Figure 12. Results from the insecticide bioassay on Melon fly (*Bactrocera cucurbitae*) reared from Kamphaeng Saen, Thailand in July, 2009. Upper figure (12A) show treatments; sugar, sugar and Abamectin and sugar and Fipronil. Down figure (12B) shows treatments nothing, Abamectin and Fipronil.

4.4. Farmer survey

The crops found in the fields of each group (chili and cucurbit) had in addition to the main crop, fruit trees and other crops close to their fields. Star fruit (*Averrhoa carambola*), rose apple (*Syzygium aqueum*), mango (*Mangifera indica*), papaya (*Carica papaya*), guava (*Psidium guajava*) are some of them. Furthermore some fields were mixed with yardlong bean (*Vigna unguiculata* subsp. *sesquipedalis*), acacia (*Acacia pennata*) and sugar cane (*Saccharum* sp).

Most of the farmers in this area have problems with fruit flies. Among the chili farmers, only one farmer (10%) answered that he did not have problems with this kind of pest. The same results were observed among the farmers that grow cucurbits. Although, the two farmers did not have any problems with fruit flies, the farmer in the cucurbit field had problems with other kinds of insects (e.g. whitefly).

The use of insecticides is widespread among the farmers interviewed. It is the most common way to control fruit flies and other insects in both chili and cucurbit fields. It was unclear whether the farmer without fruit fly problems in the chili field used insecticides to control other pests or not. Otherwise, 19 of 20 farmers used insecticides.

The insecticides used by the farmers in the cucurbit fields are cypermethrin, abamectin, carbonsulfan acetamipril, methomyl, dicrotophos and emamectin benzoate. Among the chili farmers the insecticides used are; triazophos, carbonsulfan, abamectin, cypermethrin, dichlorvos and rotenone (Figure 13). Only one farmer interviewed did not answer what kind of insecticides was used and it was in a cucurbit field. That was because she did not remember the name of the compound. Some of the farmers change insecticide each time they spray so they found it difficult to remember the name of the insecticides. On some occasions we had to look for used bottles of insecticides in the waste bin.

Most of the farmers ask in the local shop what kind of insecticides they need to purchase. Only one farmer answered that he usually consulted a close relative before he bought an insecticide.

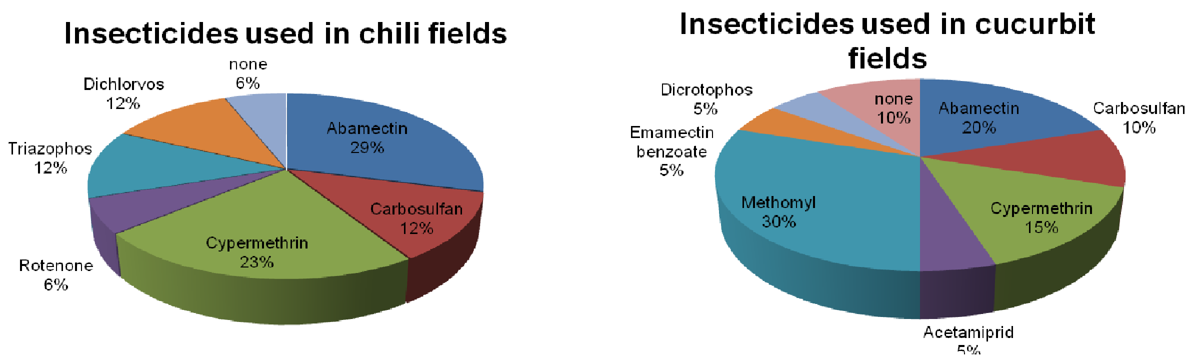


Figure 13. Percentage of insecticides used by farmers in Kampaeng Saen, Nakhon Prathom.

4.4.1 Use of insecticide

The use of insecticides in the chili fields is more regular than in the cucurbit fields. Weekly and biweekly uses of insecticides were the common answers. Cucurbit farmers use insecticides depending on whether they see any sign of attacks or not. One farmer in this group used traps baited with an attractant and an insecticide. According to him it works under a period of three months. Another farmer answered that he used insecticides as often as two - three times a week.

Five (50%) farmers in each group answered that they use the same insecticide all the time, and four (40%) farmers in each group answered that they do not use the same insecticide. Farmers belonging to the chili group sprayed more during a crop period than the farmers in the cucurbit fields. Five (50%) chili farmers sprayed between 15 and 20 times during a crop period. Four (40%) farmers in the same group answered that they sprayed 8 times or more. Two farmers in the cucurbit field (20%) answered that they sprayed between 15 and 20 times during a crop period, two farmers (20%) sprayed 5 times, one farmer (10%) sprayed 3 times. Information is lacking from three farmers because this question is one of those who were not included from the beginning. Another farmer use baited traps and he considered that the traps worked for three months. One farmer in each group did not answer because they did not have problems with fruit flies.

Four (40%) chili farmers answered that they usually sprayed in the morning, three (30%) farmers usually sprayed either in the morning or evening time. Two (20%) farmers sprayed in the evening. Cucurbit farmers have a different spraying pattern. Two farmers sprayed in the evening, one farmer in the morning and one in the afternoon. Another farmer answered that he sprayed his field anytime of day. One farmer in each group did not answer to this question because they did have any problem with fruit flies. Data for the remaining three farmers is lacking because this questions was not included from the beginning. The farmer that used traps did not need to answer to this question.

Seven (70%) chili farmers used the dose that is recommended by the label on the insecticide bottles (Table 6). One farmer answered that she used a higher dose. According to her a higher dose controls the pest more efficiently. The two remaining farmers did not answer which dosage they used. In the case of the cucurbit farmers, four farmers (40%) used the recommended dose and the remaining farmers did not give any answer.

Table 6. Dosage recommended for some insecticides purchased in Kamphaeng Saen 2009.

Insecticide (common name)	Dose (cc/20liter water)
Cypermethrin	5-10
Malathion	10-30
Fipronil	20
Methomyl	20-35
Carbonsulfan	20-30
Abamectin	30-40

Source: Respective products leaflet.

The majority of the chili farmers (6) knew that their neighbors use the same type of insecticides that they used to control fruit fly infestations. Two farmers knew that their neighbors used another kind of insecticides. Among cucurbit farmers, four of them knew that their neighbors used the same insecticide. The other four farmers answered that they neighbors did not use the same insecticides.

The question about the time of spraying before harvest showed that most of the farmers (8) that cultivated chili applied insecticide a week before they harvest the crop. Only one farmer in this group sprayed 5 days before harvest. Three of the cucurbit farmers sprayed between one and three days before harvest, one farmer did it 5 days before, four farmers sprayed one week before and another farmer did it two weeks before harvest.

4.4.2. Effectiveness of applied insecticide

Most of the farmers in both groups responded positively to the question regarding the effectiveness of insecticides. Seven chili farmers felt satisfied with the results obtained after they sprayed. Two farmers considered that the insecticides were only sometimes effective. For cucurbit farmers, seven interviewed considered that the insecticides they used were effective. Two other farmers have experienced that the insecticides worked, but only sometimes (Table 7)

Table 7. Results about effectiveness in using insecticides.

Alternatives	Chili Farmers	Cucurbit farmers
Yes	7	7
No	-	-
Sometimes	2	2
No answer	1	1

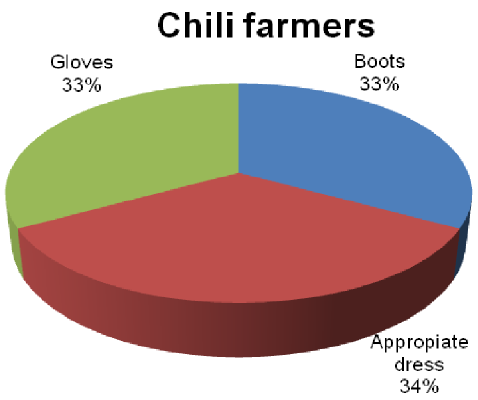
4.4.3. Application and protective measures

The application of the insecticides was done by using either knapsack or motor sprayer (Figure 14). Half of the chili producer farmers sprayed their crops by using motorized sprayers, two farmers used both knapsack or motorized sprayers and two other used only knapsack. In the cucurbit fields motor sprayer was used by four farmers, three farmers used knapsack, one farmer used both knapsack and motorized sprayer. Another farmer used only traps, according to him it was an easy way to control pests in his field and avoided coming in contact with insecticides.

Figure 14. Spray equipment used by farmers in Kamphaeng Saen, Nakhon Pathom. On the left is a knapsack and on the right is a motorized sprayer.

The farmers were asked if they use any protective clothing in connection with use of insecticides and if so were asked to specify which ones. Most of the farmers answered that they used adequate protective clothing. Seven farmers (70%) in the chili fields used personal protection and only two (20%) answered that they did not. Among the cucurbit growing farmers, five of them (50%) answered that they used protective clothing and three (30%) did not use any kind of protection. Percentage of protective equipment used among the farmers that answered positive to this question is reflected in figure 15.

Although many farmers answered that they use some kind of protective equipment my observations found the opposite. Farmers mixed the insecticides in the back yard (where, moreover, children and domestic animals spend time).



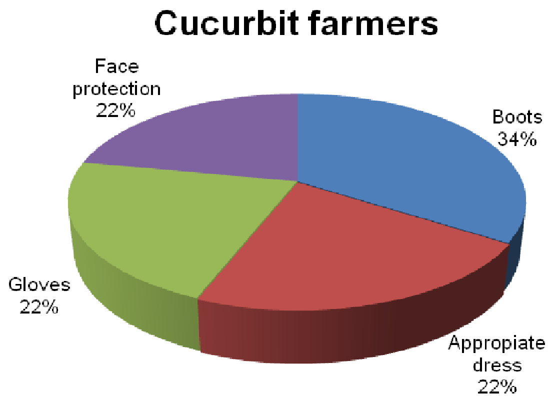


Figure 15. Percent of protective equipment used by farmers in both chili and cucurbit fields.

When the farmers were asked whether they had experienced any health complication due to the use of insecticides, the majority of them answered that they did not. Eight farmers in each group said that they have not felt any illness because of insecticides, while one farmer in each group said that they had experienced headaches and dizziness.

4.4.4 Sanitary measures

Most of farmers did not use any sanitary measure to control fruit flies. Only three chili farmers removed infested fruit from their fields. In cucurbit fields four farmers applied the any kind of sanitation measure. A list of the different sanitary measures practiced by some of the farmers interviewed follows:

- Dry fallen fruit
- Put fallen fruit in other fields
- Bury fallen fruit in the soil
- Feed fishes with fallen fruit

CHAPTER 5

5. Discussion & Conclusions

5.1. Discussion

The results from the fruit flies collected during this study suggest that the Melon fly and the Oriental fruit fly are active in the morning starting at dawn. Furthermore, I found that there are differences between the two species in number of flies caught and how long they remain active in the morning. Oriental fruit fly seems be more active between 7 am and 8 am. For Melon fly the activity time is longer. In both cases activity declines shortly before noon. The morning activity is due to the search for food after a long period of inactivity during the night (Christenson and Foote, 1960). Flies visit host and non host plants when searching for food. The temperature seems to be a regulatory element of this behaviour, since major activity is observed during early hours. Previous studies demonstrated that temperature is a very strong factor that regulates, for example, development rates and other population processes in fruit flies (Bateman, 2006). Another factor that regulates fruit fly activity is rainfall (Christenson and Foote, 1960). A preliminary suggestion of an appropriate time of day to control fruit flies in cucurbit and chilli fields may be during the first hours in morning. Nevertheless, if temperature is the regulatory factor of its activity, late afternoon time would also be possible. This is something that should be looked into. In further studies environmental factors such as air temperature, humidity and rainfall should be included in the analysis.

The number of male flies trapped in field two was, on average, greater than in field one. Nevertheless, the difference was most apparent for the Melon fly. There is a report that the sex ratio of, for example, adult Oriental fruit flies is 1:1 that means that the total population of such flies in the studied fields can be determined from the male adult population (He et al., 2002).

A very important observation from the monitoring of the diurnal activity of Fruit flies is the risk that flies could escape before the traps were collected, which would lead to a lower number of observed captured flies. Using traps with insecticide and an attractant could be part of the solution, although flies that come in contact with the insecticides and escape will fall to the ground and disappear. Experiments where different insecticides have been tested to avoid this problem showing that the choice of insecticide used in the traps is important to solve this problem (Hill, 1986).

The bioassay results indicated no signs in development of resistance to the insecticides tested. Nevertheless, it is a preliminary result and should be look into. The lack of a control population makes the test incomplete. Furthermore, it is possible that there is insecticide resistance for lower doses of insecticides; therefore a test including different dose levels is important in this study. The test suggests that when flies fed on sugar solution treated with the respective insecticide, there are indications that they take up to 48 hours for complete kill. Fipronil, however, is a quite new insecticide not used in the fields where the flies were caught. Abamectin, on the other hand, was used to a bigger degree in both cucurbit and chili fields.

This method seems to be suitable for farmers to check resistance in their fields without need of advanced tools. It is, however, very important to work with a high number of flies to be able to find resistance levels below 10% (Roush and Miller, 1986). Because of the wide use of insecticides it is important to check for insecticide resistance at least once a year. Mortality among flies treated with only insecticides and the flies that did not receive any kind of food showed similar rates of survival. Without food, flies survived less than two days at room temperature and this can be compared with earlier studies carried out by Christenson and Foote (1960) who found that fruit flies can survive at maximum of three days. The lack of food is devastating for fruit flies, which means that a control of fruit flies by taking away possible source of food by applying sanitary measures plays an important role in its survival.

Farmers in Kamphaeng Saen face problems with fruit flies. This was confirmed by a majority of the interviewed farmers. The absence of knowledge about fruit fly biology among farmers was quite striking. In some cases we had to show fruit flies to them so they would understand what the topic was about. This is a fact that makes farmers more vulnerable to sale strategies from chemical companies. A clear example is found in Malaysia, where baited methyl eugenol is frequently sold in packaging illustrated with pictures of a female melon fly. This is misleading information due to the fact that attractants do not work on female flies and methyl eugenol does not work to catch Melon flies but Oriental Fruit flies.

The use of insecticides is widespread among the farmers interviewed. All except one farmer used insecticides as the main control measure. However, the farmers were satisfied with the results of using insecticides. Thirteen farmers thought that insecticides were an effective control measure while four expressed that insecticides worked only sometimes. The effectiveness of the insecticides could be explained by the exaggerated number of applications. Many farmers sprayed their fields more than fifteen times during the growing period without following any quarantine period. Because of this, residues in food will remain high due to a great number and short interval of applications. Unfortunately, the possibilities to go away from this exaggerates use of insecticides are limited. For example organic farming in Thailand is still something very limited due to the absence of serious national certification but maybe also because of the low awareness of consumers who are not ready to pay higher prices to compensate the farmers that produce organic crops.

Another explanation can be that the farmers applied the insecticides at the appropriate time. Most of the farmers spray their fields in the morning. The results from the diurnal activity experiment suggested that this was the time when studied flies were most active (Figure 10 & 11). Nevertheless, the practice of integrated pest management (IPM) should be something to strive for because of its effectiveness and gains for the environment and health. Training farmers to become "IPM experts" is the only way to reach a sustainable production of vegetables; otherwise the use of pesticides will keep increasing (Ketelaar and Kumat, 2002). According to Verghese et al. (2004), the practice of IPM to control *B. dorsalis* can give very high reductions of infestation in mango fields. Level of reductions between 75% and 100% are possible if sanitary measures such as the removing of fallen fruit are applied. Fruit left on the ground serve as important breeding sources (Liquido, 1991). Furthermore, the use of a single control measure such as insecticides can hardly give a total reduction of fruit flies infestation since the damage done by larvae in fruit and vegetables is internal, and therefore difficult to control (Dhillon, 2005).

Farmers in this zone use a great variety of insecticides. It may be a factor that contributes to lower the risk for development of resistance since it is proved that the use of different chemicals compounds with different action mechanisms is a good method to minimize risks for development of resistance.

Most farmers did not experience any health problem due to the use of insecticides. Although, there is extensive literature that proves how serious the problems related to the exposure of insecticides are (Conway and Pretty 1991; Flessel, 1993; Kamel and Hoppin, 2004). The use of adequate protective equipment during the application of insecticides can be part of the explanation to this result given that as many as twelve farmers actually use some kind of protective equipment. However, the equipment should be renewed to give the best possible protection otherwise it could turn out to be a harmful factor instead of protective. Further investigations about possible cocktails, which mean mix of different insecticides at same time, used by farmers are very important to take into account due to farmers lack knowledge about synergistic effects.

The truthfulness from farmers when answering the questionnaires is difficult to establish but some factors that may contribute to a lower frequency of true answers in this study are the possible problems in communicating with the translator that took care of the interviews, but also leading questions that get farmers to answer in a certain way. The farmers can also sometimes make their own scores and answer in the way they think the interviewer want to hear.

The construction of traps by using old bottles is an economical way to monitor and control fruit flies but also a recycling strategy. Monitoring for the pest will give a better understanding of the number and the species present in the field. Nevertheless, development of injury thresholds for fruit flies are important to determine what control method should be use but also to establish the magnitude of the efforts. The information on injury threshold for *B. dorsalis* and *B. cucurbitae* is limited because these two pests are considered high risk quarantine pests. For international trade there is no tolerance. Detection of even 1 larva in a consignment will result in either rejection or fumigation of the consignment (Hamacek 2009, Personal information). For domestic production systems in countries where these flies are endemic it comes down to what are the acceptable losses for the producer. The traps can also be used as a direct tool in the control of these pests. By using traps baited with insecticide and an attractant can these pests be control. This is a method known as Male Annihilation Technique (MAT) which is to minimize the number of male insects. The population of flies will decrease if there are less available males to mate. The effectiveness of Steiner traps was demonstrated by Hooper and Drew (1978), where the number of catches in these traps was superior to the number of flies caught in another kind of traps.

By using traps as a direct tool in the control of fruit flies instead of cover sprays directly on crops, the reduction of trace of insecticides in the field and in crops are some of the benefits. Furthermore, the farmers do need to come in contact with insecticides in such a prolonged and intensified manner as when cover spraying. Apart from its effectiveness, this method is also very easy to use and perform on trial basis (Mirani, 2007).

The situation in Thailand's agriculture is definitely unsustainable and must be changed for the best of the farmers, consumers and the environment. The knowledge of alternative control methods for fruit flies is quite big and has to be put in practice. Successful results when practicing different cultural methods like for example sanitary measures show that there are possibilities to control fruit flies with other tools than insecticides. Of course the solution does not only lay on this kind of measure but we have to congregate other control methods like for example biocontrol by releasing of parasitoids but also taking measures to conserve the already existing natural enemies in the fields. That in conjunct with traps baited with insecticides can guarantee a moderate use of insecticides. Furthermore, training farmers to better understand the consequences of using insecticides are an important step in the efforts to go away from relies on chemicals and also an increasing of stimulant for farmers to start produce organic food should contribute to a better sustainable farming.

5.2. Conclusions

The conclusions that can be drawn out of this study are the following:

1) The preliminary results suggest Fruit flies to be more active during the morning. Therefore, for management of both Melon fly and Oriental fruit fly, the control efforts

should be made during the time interval 6 am and 10 am. However further and more intensive studies should be made to validate these results.

2) The modified traps worked very effectively. Nevertheless, it is important to be attentive to contamination risks in the outer parts of the traps, since small amounts of attractant on the surface of the trap may disturb the flies and they will not go inside the trap. The traps have a potential to obtain information on the abundance and species composition of fruit flies in the field, information that is needed to determine whether a control measure is needed or not, but traps also have a potential as a tool in the control of the pest by mass trapping or disruption in mating.
3) The bioassay indicated no signs of development of insecticide resistance. Nevertheless, it is important to follow this experiment more intensively but also including other insecticides that according to the farmers interviewed are used more frequently as for example methomyl, cypermethrin and carbonsulfan. Also tests by using different dose levels of insecticides are important in testing for resistance.
4) Farmers rely on insecticides to control these two fruit fly species. Therefore, prolonged studies on the consequences of this exaggerated control method should be made. Furthermore, it is urgent to train farmers in the use of sustainable control measures to approach integrated pest management.

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Appendices

Appendix A

Weather data for July and August 2009, Nakhon Prathom meteorological station. The highlighted cells represent the days when the diurnal activity experiments were carried out.

Date (July)	Air Temperature(°C)			Date (August)	Air Temperature(°C)		
	Max.	Min.	Mean		Max.	Min.	Mean
1	31,6	24,0	27,8	1	32,7	24,3	28,5
2	34,7	24,2	29,5	2	33,5	24,7	29,1
3	34,3	24,2	29,3	3	33,7	24,8	29,3
4	34,0	24,6	29,3	4	35,0	24,6	29,8
5	31,7	24,4	28,1	5	34,7	25,2	30,0
6	31,7	23,4	27,6	6	32,7	25,2	29,0
7	32,9	23,2	28,1	7	30,0	25,0	27,5
8	32,3	23,3	27,8	8	33,2	25,4	29,3
9	34,0	23,5	28,8	9	30,8	24,8	27,8
10	35,0	24,2	29,6	10	32,8	24,5	28,7
11	35,5	25,7	30,6	11	35,1	24,4	29,8
12	35,8	25,9	30,9	12	36,4	24,6	30,5
13	29,9	24,0	27,0	13	36,5	25,6	31,1
14	29,9	23,9	26,9	14	34,4	24,0	29,2
15	32,7	24,0	28,4	15	35,9	25,2	30,6
16	31,6	25,4	28,5	16	35,2	24,0	29,6
17	33,2	25,2	29,2	17	36,0	23,6	29,8
18	31,7	24,6	28,2	18	34,3	23,5	28,9
19	33,6	24,8	29,2	19	36,2	24,0	30,1
20	32,2	24,8	28,5	20	36,3	22,7	29,5
21	34,3	25,1	29,7	21	36,2	24,6	30,4
22	32,3	23,5	27,9	22	36,1	24,0	30,1
23	30,8	23,3	27,1	23	35,3	23,9	29,6
24	33,6	23,5	28,6	24	34,0	24,5	29,3
25	31,9	23,0	27,5	25	35,6	23,2	29,4
26	32,9	24,2	28,6	26	36,3	24,3	30,3
27	33,7	23,7	28,7	27	35,7	23,7	29,7
28	33,9	22,6	28,3	28	33,3	24,0	28,7
29	32,0	24,3	28,2	29	33,2	23,7	28,5
30	32,5	24,7	28,6	30	31,8	26,0	28,9
31	32,6	24,6	28,6	31	32,7	25,3	29,0
Total	1 018,8	749,8	884,3	Total	1 065,6	757,3	911,5
Mean	32,9	24,2	28,5	Mean	34,4	24,4	29,4

Appendix B
Interview questions

Date	Location	Parish

1. Do you have any problems with fruit flies in your orchard?

Yes ☐ ☐ No

2. In which crops you use to have problem with fruit flies?

   ....

   ....

3. How do you control the fruit flies?

   ....

   ....

4. If you use insecticides, what kind of insecticides do you use?

   ....

   ....

5. How do you know which insecticide (s) you need to purchase?

   ....

6. How often do you use the insecticides?

   Every 2-3 days ☐ weekly ☐ monthly ☐

   When you see signs of attacks ☐

   Other..

7. Do you use the same insecticide(s) all the time?

Yes ☐ No ☐

If No, how often you change the insecticide(s)..

8. How many times do you spray your crops (during crop period)?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Other..............................

9. When in the day do you use to apply the insecticide(s)? (If possible indicate time)

Morning ☐ time ....

Afternoon ☐ time ....

Evening ☐ time ....

10. How do you estimate the dose of insecticide?

....

....

11. How many days between each spraying?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

More than 1 week ☐

12. Do you know if your neighbours use the same kind of insecticide that you use?

Yes ☐ ☐ No

13. Are the insecticides effective?

Yes ☐ Sometimes ☐ No ☐

14. How do you apply the insecticides?

....

....

15. Do you use any protective equipment when spraying your crop?

Yes ☐ ☐ No

If yes;
Gloves ☐
Appropriate dress ☐
Boots ☐
Face protection

Other.................................... ☐

16. Have you experienced any of following symptoms after use of insecticides?

Vomit ☐

Headache ☐

Fainting ☐

Eye itch ☐

Nose bleed ☐

"Burns" ☐

No ☐

Other problems..

17. Do you apply any sanitation measures to control fruit flies?

- Remove infested fruits ☐
- Leave infested fruits in the field ☐

If you remove infested fruits, what do you do with them?

☐

- Bury infested fruits in the soil

- Feed fishes with infested fruits to in pounds ☐

Other...

18. How long time before harvest do you applied insecticides to the crops?

1 week ☐ 3 weeks ☐ 2 weeks ☐

Other..........................

Thank you very much.