BIOLOGY AND POPULATION DYNAMICS OF MANGO FLOWER THRIPS (THYSANOPTERA) AND EFFECTIVENESS OF NEEM (*AZADIRACHTA INDICA*) OIL FOR THEIR CONTROL

by

HAMASEH ALIAKBARPOUR

Thesis submitted in fulfillment of the requirements

for the degree of

Doctor of Philosophy

October 2011

ACKNOWLEDGEMENTS

I would like to thank all those who contributed and helped me while in the process of completing my degree at Universiti Sains Malaysia. First of all, I wish to express my sincere appreciation to my supervisor, Prof. Che Salmah Md. Rawi for her intellectual discussions and insightful suggestions. I feel honored that I had the opportunity to work under her guidance. I wish to express my gratitude to Dr. Laurence Mound at CSIRO Ecosystem Sciences, Canberra, Australia for his remarkable advice and guidance while identifying the collections. I am much indebted to Dr. Surakrai Permkan at Department of Pest Management, Faculty of Natural Resources, Prince Songkla University, Hat Yai, Thailand for kindly verifying thrips specimens. I would like to extend a special thank to Agricultural office of Balik Pulau district, especially to Mr. Hedzir Ill Yasak, who offered his assistance in providing a location to carry out this research.

My appreciation is extended to Prof. Abu Hassan Ahmad, Dean of School of Biological Sciences, for facilitating this research both in the laboratory and in the field. I would like to thank Dr. Hamady Dieng at School of Biological Sciences for his valuable remarks. My thanks are due to the technicians of School of Biological Sciences, who have helped me in my experimental works. I wish to thank Mrs. Rosmida Mat Ali at Institut Pertanian Bumbong Lima, Seberang Perai for training in slide preparation of thrips. I greatly appreciate Universiti Sains Malaysia short term grant and USM fellowship for providing financial support for this research. I would like to thank my parents for their unfailing support through all my years of growing up. Finally, I wish to thank my husband, who tirelessly supported me during my research. His understanding and encouragement through the years strongly inspired me to finish my research.

TABLES OF CONTENTS

Chapter 6 - Population dynamics of various thrips species inhabiting mango panicles in treated and untreated orchards

Chapter 8 - Spatial patterns of various thrips species in treated and untreated mango orchards

Chapter 9 - Diurnal activity of main mango pollinators and efficacy of neem oil against thrips (Thysanoptera) on mango panicles and its compatibility with mango pollinators

Chapter 10 - General conclusions and recommendations

LIST OF TABLES

LIST OF FIGURES

BIOLOGI DAN DINAMIK POPULASI THRIPS BUNGA MANGGA (THYSANOPTERA) DAN KEBERKESANAN MINYAK NEEM (*AZADIRACHTA INDICA*) UNTUK PENGAWALANNYA

ABSTRAK

Dinamik populasi thrips telah dikaji di ladang mangga yang dirawat dan tidak dirawat dengan racun perosak di Balik Pulau, Pulau Pinang antara tahun 2008 dan 2010. Kelimpahan thrips telah dianggar secara memungutnya dari panikel bunga mangga dan beberapa spesies rumpai yang tumbuh di dalam ladang. Empat spesies thrips dari famili Thripidae; *Thrips hawaiiensis*, *Scirtothrips dorsalis*, *Frankliniella schultzei* and *Megalurothrips usitatus* telah direkod diladang yang dirawat. Selain dari species ini, *Thrips palmi* (Thripidae) and *Haplothrips* sp. (Phlaeothripidae) telah ditemui di ladang yang tidak dirawat. Perbandingan antara beberapa teknik pemungutan thrips dengan pengiraan populasi absolut menunjukkan, kaedah pemungutan dengan CO_2 adalah paling efisien dan menangkap 80.7% thrips dewasa, diikuti oleh kaedah membasuh (62.3%) dan kaedah menggoyang (36.4%). Semua teknik penangkapan menunjukkan bilangan spesies thrips pada panikel bunga memuncak antara 1200 h dan 1400 h. Penilaian terhadap aktiviti penerbangan diurnal yang berguna untuk menentukan masa pemungutan dan mengawal perosak ini menunjukkan thrips dewasa yang ditangkap dengan perangkap pelekap kuning sangat melimpah antara 0800 h -1000 h and 1600 h-1800 h. Perangkap pelekap juga didapati boleh dipercayai untuk mengawasi populasi thrips di ladang mangga. Tahap agregasi thrips dewasa pada panikel bunga adalah lebih tinggi dan signifikan pada ladang yang dirawat berbanding dengan ladang yang tidak dirawat tetapi larva bertabur secara normal di kedua ladang. Kepadatan larva thrips yang jatuh ke dalam tanah untuk menjadi pupa telah ditentukan dengan menggunakan perangkap jatuh. Kemunculan thrips dewasa yang ditangkap di dalam perangkap 'kemunculan' menhasilkan maklumat paten generasi beberapa spesies thrips di dusun mangga tersebut. Pengangaran kepadatan larva yang akan menjadi pupa menggunakan perangkap gugur dan penjelmaan thrips dewasa pada perangkap jelmaan menghasilkan peratus penjelmaan dewasa dari tanah yang lebih rendah pada musim hujan berbanding dengan musim kering. Jarak dan arah penyebaran thrips dewasa tidak dipengaruhi oleh arah tiupan angin dan lebih banyak thrips bergerak ke arah kawasan tanaman. Populasi thrips yang ditangkap dengan perangkap pelekap berkurangan seiring dengan pertambahan jarak dari ladang mangga. Semua pendebunga bunga mangga sangat aktif pada awal pagi dan lewat petang. Mortaliti thrips dewasa (68.7%) dan larvae (80.7%) yang dirawat dengan imidacloprid menunjukkan keberkesanan racun yang tinggi kepada perosak tetapi ianya sangat toksik dan telah mengurangkan 92.5% populasi pendebunga. Antara tiga kepekatan minyak neem (1%, 2% and 3%) yang digunakan untuk mengawal thrips, minyak neem 2% adalah lebih berkesan (mortaliti 59.8%), 96 jam selepas aplikasi racun yang kedua yang hanya mengurangkan 24.9% kepadatan pendebunga.

BIOLOGY AND POPULATION DYNAMICS OF MANGO FLOWER THRIPS (THYSANOPTERA) AND EFFECTIVENESS OF NEEM (*AZADIRACHTA INDICA*) OIL FOR THEIR CONTROL

ABSTRACT

Population dynamics of thrips was investigated in treated and untreated mango orchards, located at Balik Pulau, Penang between 2008 and 2010. Thrips abundance was estimated by collecting them from mango panicles and various weed species growing in the orchard. Four thrips species from the family Thripidae; *Thrips hawaiiensis*, *Scirtothrips dorsalis*, *Frankliniella schultzei* and *Megalurothrips usitatus* were recorded from the treated orchard. Other than these species, *Thrips palmi* (Thripidae) and *Haplothrips* sp. (Phlaeothripidae) were encountered in the untreated orchard. Comparing several thrips collection techniques with the absolute population count, CO_2 collection method was the most efficient procedure, extracting 80.7% adults, followed by the washing procedure (62.3%) and the shaking method (36.4%). All collection techniques showed that the numbers of all thrips species in mango panicles reached a daily peak between 1200 and 1400 hrs. Assessment of diurnal flight activity, which is useful for effective timing of sampling and controlling of this pest, had shown that adult thrips captured on the yellow sticky traps were the most abundant between 0800-1000 and 1600-1800 hrs. Sticky trap was also found to be satisfactorily reliable to monitor thrips populations in mango orchard. The level of aggregation of thrips adults on mango panicles was significantly higher in the treated orchard than in the untreated orchard, but the larval distribution was found to be normal in both orchards. Densities of larval thrips falling into the soil to pupate were determined using a drop trap. Emerging thrips

adults captured in an emergence trap provided information on generation patterns of various thrips species in the mango orchards. Percentage of adult emergence from the soil was lower in the wet season than recorded in the dry season. Thrips dispersal distance and direction of their movement were not affected by directions of wind blow and more thrips moved towards areas with vegetation. Population of thrips captured using sticky trap decreased with increasing distance from the mango orchard. All mango pollinators showed their highest activity in early morning and late afternoon. High mortalities of thrips adults (68.7%) and larvae (80.7%) treated with imidacloprid reflected its high efficacy against the pest, but was highly toxic and reduced 92.5% of pollinators' population. Among three concentrations of neem oil (1%, 2% and 3%) used to control thrips, 2% neem oil was more effective (59.8% mortality), 96 h after the second application with only 24.9% reduction in density of pollinators.

Chapter 1

Introduction

1.1 Background

This study involves an investigation of ecology and control of various thrips species infesting mango (*Mangifera indica* L.) inflorescences on Penang Island, Malaysia. Mango is a heavily consumed fruit in Malaysia, where is regarded as one of the most important mango producers in the world (Swirski et al., 1997). Malaysia lies within equatorial region with heavy precipitation, high temperature and humidity, which are the favourable factors for mango production. In Malaysia, mango cultivation is expanding due to the popularity of this fruit and ever increasing demand for fresh and processed mango products. The domestic consumption of mango increased from 42,634 MT (2002) to 55,901 MT (2005) (Mirghani et al., 2009).

However, this commodity is threatened by the presence of thrips, which have been ranked among the most destructive pests worldwide, due to the range of crops attacked by thrips, their small size, their ability to disperse widely, to multiply rapidly and to cause direct feeding damage and plant virus transmission (Lewis, 1997a; Morse and Hoddle, 2006). Thysanoptera occur worldwide, mostly in tropical regions, with many temperate and a few arctic species (Mound, 1997; Morse and Hoddle, 2006). Feeding and oviposition of thrips on different parts of mango such as panicles, leaves and young fruits cause scarring and deforming very early in the life of the fruits, resulting in unmarketable fruits (Higgins, 1992; Pena et al., 2002). Saliva injection of thrips prior to sucking the cell content enables them to act as vectors of plant viruses (Kirk, 1997a).

Thrips pose difficulties in sampling due to their small size compared to larger insects inhabiting plants and congregation in tight places on their hosts (Southwood, 1978). Visual inspection of flowers is a common monitoring technique for thrips (Pena, 1993; Pena et al., 1998). However, interpreting the number of individuals present on crops is difficult in visual assessment of infestation level (Lewis, 1997a). Hence, awareness of a sampling technique that efficiently estimates thrips population is critical to study thrips population abundance and construct a pest management program. Investigation on the diurnal pattern of thrips abundance on mango panicles will determine effective timing for sampling and controlling this pest in mango orchards. The development of sustainable approaches for managing thrips requires accurate species identification and understanding the behaviour and ecology of thrips. Knowledge on bionomics, life cycle and biological traits is essential for effective control of thrips. The focus of the research presented is identification of different thrips species and investigation on spatial and temporal distribution, which provide basic information for future monitoring and sampling programs.

Thrips are polyphagous insects capable of developing on a number of cultivated and wild host plants (Katayama, 2006). Since these wild plants may be of importance as refuge areas for thrips development, determination of weed host range and abundance of thrips species on wild host plants is essential to understand the seasonal natural history of thrips, degree and timing of infestation of cultivated crops. Population of thrips occurring on the surrounding vegetation affects the presence of thrips in crop fields (Stoltz and McNeal, 1982; Chellemi et al., 1994 and Pearsall and Myers, 2001).

Indiscriminate use of synthetic insecticides for routine thrips control is detrimental to non-target organisms and causes pesticides residues on food and in the environment. However, not only does insecticide use pose a threat to human and environmental health, these pesticides are showing decreasing effectiveness due to the development of resistant pest populations, pest resurgence and the outbreak of secondary pest infestations (Weisenburger, 1993; Tinker, 1997; Horrigan et al., 2002 and Desneux et al., 2007). Neonicotinoids such as imidacloprid are applied effectively as foliar applications to control thrips. The usage of synthetic pesticides in East, Southeast Asia and China increased from 0.74 kg/ha in 1989-91 to 1.5 kg/ha in 1998-2000 (FAO, 2003).

To minimize harmful effects of synthetic pesticides, development of non-polluting plant protection is needed. Currently, a rising interest in the use of neem products in integrated pest management (IPM) strategies is observed. Neem products are important components in integrated pest management concepts as a result of study on the bioactive ingredients of the neem tree, *Azadirachta indica* A. Juss. (Meliaceae) (Ermel et al., 2002). Neem seed extracts have considerable broad-spectrum toxicity against a number of agricultural pests and pathogens (Quarles, 1994), have less risk of inducing resistance in insects (Feng and Isman, 1995) and are relatively nontoxic to mammals (Weinzierl and Henn, 1991; Thoeming and Poehling, 2006). Short persistence of neem ingredients in environment has particular significance for their use in IPM (Ermel et al., 2002).

Different registered neem formulations have been classified as safe for environment and non-target organisms such as pollinators (Schmutterer, 1997; Immaraju, 1998), which are crucial to the maintenance of all wild plant communities and agricultural productivity (Kevan, 1999; Ashman et al., 2004 and Klein et al., 2007) and considered as indicators of ecosystem health for study the effect of a pressure such as pesticides (Kevan, 1999). The awareness and demand for pesticidefree products is increasingly expanding throughout the world. Thus, sustainability in agriculture with reduced use of harmful pesticides has been encouraged.

1.2 Objectives

The main objectives of this thesis are:

1. Identification of thrips species within mango panicles and weed plants in mango orchards on Penang Island, Malaysia.

2. Evaluation of efficiency of three non-destructive sampling techniques for determination of relative density of thrips species in mango panicles.

3. Investigation on population dynamics of thrips species inhabiting mango panicles in mango orchards.

4. Measuring the spatial distribution of thrips in mango panicles.

5. Comparison of the efficacy of neem oil with imidacloprid, a commonly used insecticide, against thrips infesting mango panicles and their effects on mango pollinators.

Chapter 2

Literature review

2.1 Mango (*Mangifera indica* L.)

Mango, *Mangifera indica* L., a member of the family Anacardiaceae, is the most economically important cultivated species in the genus *Mangifera*, which was spread to Malaya and eastern Asia in the 4th and 5th centuries BC (Kwee and Chong, 1994). With a world mango production exceeding 2.6×10^7 ton, it is one of the most esteemed fruits and known as king of fruits throughout the tropical lowlands (Mirghani et al., 2009; Ndiaye et al., 2009). Popularity of mango is mainly due to its high nutritive and medicinal values. Unripe mango is a rich source of vitamin C and the ripe fruit contains pro-vitamin A and vitamin C (Hussain et al., 2002; Ara et al., 2005).

Mango, originated from India and Southeast Asia (Kostermans and Bompard, 1993), is best grown in tropical areas with seasonal rains (Dag et al., 2000). However, it is widely cultivated in hot subtropical regions such as Australia, Brazil, Egypt, Florida, Israel, northern India, Spain and South Africa. The highest number of mango variety occurs in Peninsular Malaysia, Java, Sumatra and Borneo (Kostermans and Bompard, 1993; Bally, 2006). In Malaysia, mango is one of the most consumed fruits with approximately 4,565 hectares agricultural land area under mango plantation (Table 2.1). The genus, *Mangifera* consists of 70 species and approximately 28 species are found in Malaysia (Kwee and Chong, 1994; Ian, 2006).

Table 2.1 Areas (hectares) under mango cultivation in Peninsular Malaysia (Kwee and Chong, 1994).

State	Total sole crop equivalent	Sole crop area	Main crop area	Mixed crop area
Johor	301	97	94	266
Kedah	594	94	66	901
Kelantan	405	151	70	404
Melaka	148	23	-	251
Negeri Sembilan	519	83	194	580
Pahang	215	101	94	87
Perak	959	120	-	1,678
Perlis	59	-	40	58
Pualu Pinang	58	-	-	115
Selangor	751	81	-	1,341
Terengganu	556	205	215	379
Total	4,565	955	773	6,060

In Peninsular Malaysia, there are over 300 varieties of mango with fruits varying considerably in size, shape, colour, flavour and fibre content. Common commercially planted cultivars include Harumanis (MA 128), Sungei Siput (MA 159), Golek (MA 162), Maha (MA 165), Malgoa Ramasamy (MA 200), Bombay Green (MA 203), Mas Muda (MA 204), Siam Panjang (MA 205), Karutha Kolumban (MA 217), Nam Dok Mai (MA 223) and Chok Anan (MA 224). Relatively uniform temperature of Malaysia lies within the optimum temperature range for mango, i.e., 24ºC to 27ºC.

Mango has a lower limit of 1-2 ºC and a higher limit of 43 ºC for vegetation (Kwee and Chong, 1994).

The inflorescence of mango is a terminal panicle with several hundred pale pink to white flowers. Two flower forms, hermaphrodite (perfect) and male (staminate), occur on the same inflorescence. Hermaphrodite flowers vary from 3% to 30% depending on variety, climate and soil conditions (Kwee and Chong, 1994). A mango inflorescence may possess 1,000 to 4,000 flowers that are rich source of nectar (Bally, 2006). A dry season prior to and during the flowering period is essential for good fruit production (Mossler and Nesheim, 2002). Rainfall and high humidity during flowering and fruit development decrease fruit yields and are conducive to the development of fungal diseases causing flower and fruit drop (Bally, 2006).

2.2 Pests of mango panicles

Mango is usually infested by several pests during its growth from seedling until fruit maturity. Of 260 species of pest insects attacking this crop, 196 species feed on inflorescences, buds and foliage. Midges, caterpillars, leafhoppers, thrips and mites are considered as the most significant pests attacking mango inflorescences (Pena et al., 1998). *Anomala cupripes* (Hope), *A. pallida* (Fabricius) and *Apogonia expeditionis* (Ritsema) (Coleoptera: Scarabaeidae), *Tabanus* spp. (Diptera: Tabanidae), *Asota producta* (Butler) (Lepidoptera: Noctuidae) were reported as pests of mango flowers in Chuping, Perlis, Malaysia (Abdullah and Shamsulaman, 2008). Butani (1979) collected cecidomyiid gall midge species, *Erosomya indica* (Grover and Prasad) and *E. mangiferae* (Felt) (Diptera: Cecidomyiidae) from mango panicles. Some species of leafhoppers such as *Idioscopus clypealis* (Leth.), *I. niveosparsus* (Leth.), *I. nagpurensis* (Pruthi) (Homoptera: Cicadellidae) and *Amritodus atkinsoni*

(Leth.) (Homoptera: Jassidae) were considered as important pests of mango panicles (Soomro et al., 1987).

Whitwell (1993) reported *Chloropteryx glauciptera* (Hampson) and *Oxydia vesulia* (Cramer) (Lepidoptera: Geometridae) within mango panicles in Dominica. The microlepidoptera complex attacking mango inflorescences in Florida consists of *Pococera atramentalis* (Lederer) (Pyralidae), *Pleuroprucha insulsaria* (Guenee) (Geometridae), *Platynota rostrana* (Walker) (Tortricidae), *Tallula* spp. (Pyralidae) and *Racheospila gerularia* (Hubner) (Geometridae) (Pena, 1993). Fluted scale, *Icerya aegyptiaca* (Douglas) and *I. seychellarum* (Westwood) (Homoptera: Margarodidae) attack mango flowers (Pena et al., 1998). Immature and adults of tea mosquito bug, *Helopeltis pernicialis* (Stonedahl et al.) (Hemiptera: Miridae) cause black necrotic lesions on flower panicles. Dimpling bug, *Campylomma austrina* (Malipatil) (Hemiptera: Miridae) sucks sap of flowers and developing fruits, which causes dimpling of young fruits (Chin et al., 2002).

2.3 Thrips systematic

Thrips are among the smallest winged insects, ranging from 0.5 to 15 mm in length, mostly with band-like wings delicately fringed with long cilia (Lewis, 1973). First, these insects were called *Physapus* by De Geer (1744), but Linnaeus renamed these insects to *Thrips* in 1758 (Lewis, 1997a). Thrips are presumed to have a common ancestor with the orders Hemiptera, Psocoptera and Phthiraptera (Mound, 1997). Of an estimated 8,000 extant species, nearly 6,000 species of thrips are currently recognized worldwide (Mound, 2009). They are placed under the order Thysanoptera that divided into two suborders; Tubulifera and Terebrantia (Mound et al., 1980). The members of these suborders differ in the shape of their ovipositor.

Terebrantian females have a saw-like ovipositor to lay egg into the plant tissue (Figure 2.1). Their wings lie parallel to each other at rest. The members of suborder Tubulifera have a tube-like ovipositor (Figure 2.2), which deposit egg on the surface of the plant and their wings overlap at rest (Lewis, 1973). Approximately 60% of Tubuliferan species are fungivores, whereas more than 95% of Terebrantia are associated with green plants (Mound, 2005). The morphological features in thrips adults are well defined. However, identification of the larval thrips is a difficult task as the taxonomy of thrips larvae is poorly developed (Kucharczyk, 2004). Important taxonomic characters used for identification of larval thrips were illustrated in Figure 2.3.

The suborder Tubulifera contains only one family, Phlaeothripidae, with approximately 3,500 described species, whereas the Terebrantia comprises eight families with about 2,400 species (Mound and Minaei, 2007) (Table 2.2). Most of the crop damaging thrips belong to the family Thripidae, particularly two genera, *Thrips* and *Frankliniella* (Mound, 1997). *Thrips* with 280 described species is the largest genus in this insect order (Ng et al., 2010), followed by *Liothrips* (250 species) and *Haplothrips* (230 species) (Mound and Zapater, 2003; Mound, 2009). Twenty three species belonging to the genus *Thrips* were identified in Malaysia. *Frankliniella occidentalis* and *F. intonsa* were numerous in highland areas and African species, *Ceratothripoides brunneus* was found commonly in lowland areas (Mound and Azidah, 2009). More than 90% of thrips species are placed in the Thripidae or Phlaeothripidae (Mound, 1997), which are normally found on crops. Within the subfamily Phlaeothripinae two genera, *Haplothrips* and *Liothrips*, are plant feeding and considered as crop pests (Mound, 1997; Minaei and Mound, 2008).

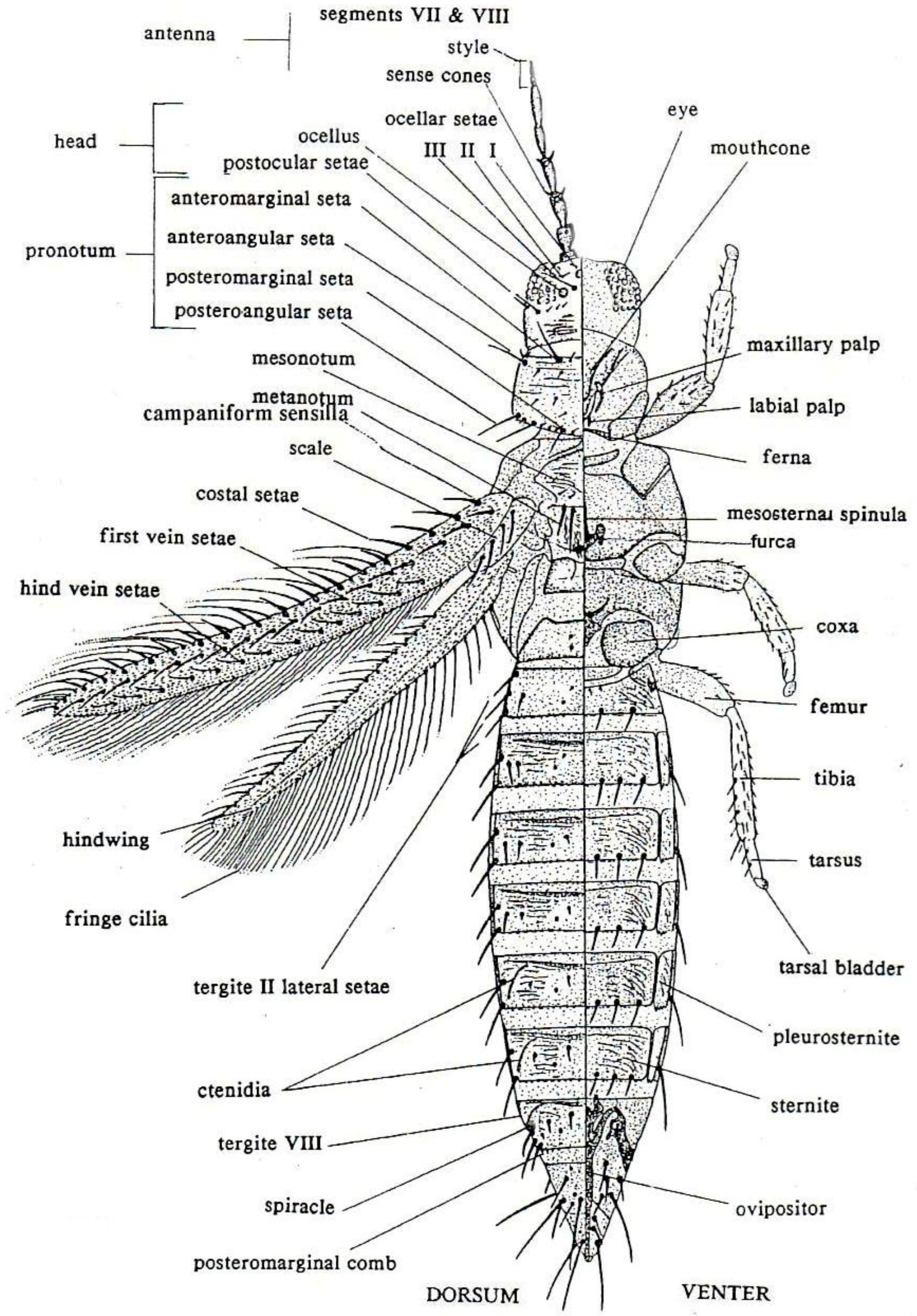

Figure 2.1 Taxonomic characters used for identification of Terebrantian thrips adults (Thripidae) (Mound, 2007).

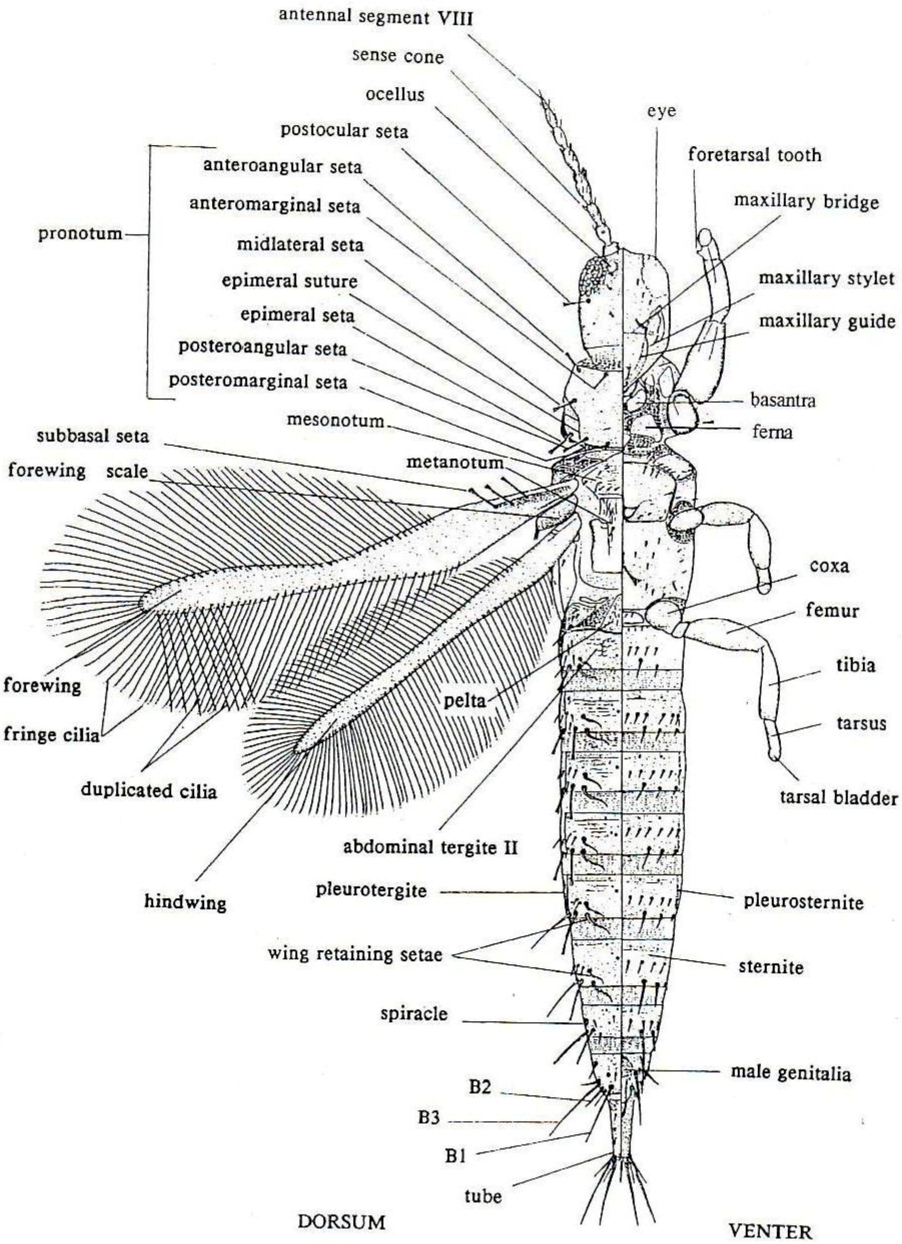

Figure 2.2 Taxonomic characters used for identification of Tubuliferan thrips adults (Phlaeothripidae) (Mound, 2007).

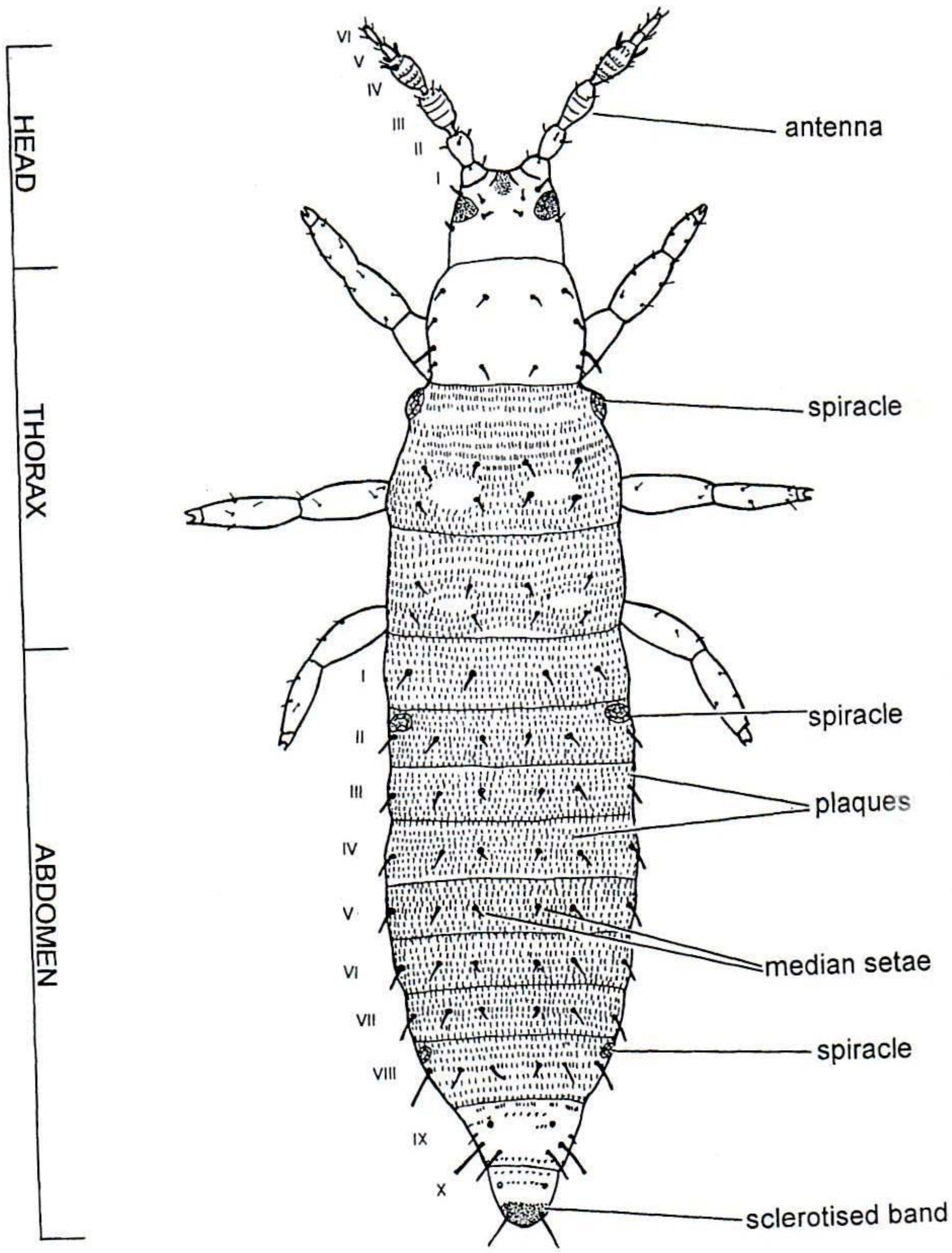

Figure 2.3 Taxonomic characters used for identification of larval thrips (Milne et al., 1997).

Thrips species are identified based on external morphological characteristics such as colour and chaetotaxy, head shape, number of antennal segments, arrangement of the prothoracic and wing setae, sculpture of the metanotum and shape of the pelta (in Tubulifera) (Moritz et al., 2004; Mound, 2009). Sex differentiation is relatively simple in Terebrantia than in Tubulifera. Males of Terebrantia have elongated abdomen rounded at tip and they are always smaller and paler in colour than females. In Tubulifera, males are often stouter than females with enlarged forelegs. The female bears a short internal rod lying at the base of the tube (abdominal segment), which can be difficult to identify (Lewis, 1973).

Table 2.2 Thysanoptera classification with total genera and species (Mound, 1997 and 2009).

Suborder	Family	Subfamily	Genus	Species
Tubulifera	Phlaeothripidae	Phlaeothripinae	370	2,800
		Idolothripinae	80	700
Terebrantia	Uzelothripidae	-	1	1
	Merothripidae	-	3	15
	Melanthripidae	-	4	65
	Aeolothripidae	-	23	190
	Fauriellidae	-	4	5
	Adiheterothripidae	-	3	6
	Heterothripidae	-	4	70
	Thripidae	Panchaetothripinae	40	135
		Dendrothripinae	15	100
		Sericothripinae	3	150
		Thripinae	230	1,650

2.4 Thrips host range

2.4.1 Cultivated host plants

Thrips frequently inhabit inflorescences, shoots, tender leaves and fungus-infested dead or decaying wood (Ananthakrishnan, 1993a). Although flower-living thrips feed on pollen and flower tissues, some thrips species play an important role in successful pollination of the plants on which they live (Ananthakrishnan, 1993b; Williams et al., 2001). The species of Merothripidae and the single species of Uzelothripidae are all fungivores. Little is known about the host range of different species of Fauriellidae. Most of the species of Adiheterothripidae are found in the flowers of date palm (*Phoenix dactylifera* L.) between the Mediterranean and India. Species of Heterothripidae have been collected from the flowers of a wide range of American plants. Species of Aelothripidae show different range of feeding habits, from completely phytophagous to fully predacious (Mound, 1997).

The most destructive crop pests are recorded in the family Thripidae. The members of subfamily Panchaetothripinae feed on the leaves of green plants. The greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouche) and the red-banded cocoa thrips, *Selenothrips rubrocinctus* (Giard) prefer to feed on senescing leaves. However, several species of *Caliothrips* are pests of seedling crops. Members of Dendrothripinae feed on very young leaves, especially in tropical countries. Species of Sericothripinae live on flowers and leaves such as *Neohydatothrips pseudoannulipes* (Johansen), which are severe pests of garden plant *Tagetes*, the African marigold (Mound, 1997). The majority of Thripidae species belong to the subfamily Thripinae. A great number of these species feed on grasses and florets (*Chirothrips* and *Limothrips*) and other on leaves (*Aptinothrips* and *Stenchaetothrips*) and a few species are predators of spider mite (*Scolothrips*). A small group of tropical species feed on mosses, whereas many species feed particularly on pollen and other flower parts (Mound and Marullo, 1996).

Species of subfamily Idolothripinae (Tubulifera) feed only on fungal spores, but the subfamily Phlaeothripinae comprises many plant feeding species, especially the genus *Haplothrips* (Mound and Marullo, 1996), which live in flowers, particularly of Compositae, Gramineae, Asteraceae, Poaceae, Juncaceae and Cyperaceae (Mound, 1997). *Haplothrips* species rarely breed on the leaves of plants (Minaei and Mound, 2008). Some species are predators of mites, lepidopteran eggs and immature stages of scale insects and whiteflies (Mound, 1997).

A few number of the most advanced flower thrips including *Thrips tabaci* (Lindeman), *Frankliniella occidentalis* (Pergande) and *F. schultzei* (Trybom) feed on both flowers and leaf tissues (Mound, 1997). *Thrips razanii, a member of the Thrips hawaiiensis group, was collected from the flowers of various plants in Peninsular Malaysia (Ng et al., 2010). Thrips palmi* (Karny) is a major pest on several crops including mango, cucumber, watermelon, cotton, cowpea, melon, potato and some weed species (Nagai and Tsumuki, 1990; Walsh et al., 2005 and Cannon et al., 2007). *Frankliniella occidentalis* infests vegetable crops such as cucumber, onion, pepper, potato, lettuce and tomato (Capinera, 2001). *Frankliniella schultzei* attacks a wide range of host plants such as sorghum, peanut, pea, bean, mango, cotton, pepper, onion and tomato (Chin et al., 2006). *Megalurothrips* species are especially destructive pests of bean and soybean (Chang, 1987). *Thrips hawaiiensis* (Morgan) is a severe pest of various crops such as tobacco, gladiolus, coffee, tea, mango, citrus, apple, pear, banana, passion fruit and rose (Hollingsworth, 2003; Reynaud et al., 2008). *Scirtothrips dorsalis* (Hood) causes economic damage to mango, citrus, grapevine, tea, castor, chilli, strawberry, peanut, soybean, sweet potato, tobacco, tomato and other fruits and ornamental crops (Seal et al., 2006b; Masui, 2007).

2.4.2 Uncultivated host plants (wild plants)

Since thrips have a broad host range, not only crops, but also wild plants growing around the fields are considered to be reservoirs. Weeds can serve as a refuge during pesticides application (Katayama, 2006). *Frankliniella occidentalis* was collected from 49 weed species such as *Amaranthus albus* (Amaranthaceae), *Ammi visnaga* (Apiaceae), *Anthemis cotula* (Asteraceae), *Echium plantagineum* (Boraginaceae) and *Neslia paniculata* (Brassicaceae) in vegetable production area in Turkey (Atakan and Uygur, 2005). It was also recovered from eight weed species including *Senecio vulgaris* (Asteraceae), *Lamium amplexicaule* (Lamiaceae), *Vicia angustifolia* (Fabaceae) in Japan (Katayama, 2006). In Georgia, important reproductive host for this thrips species is wild radish, *Raphanus raphanistrum* (Brassicaceae) (Buntin and Beshear, 1995). Pearsall (2002) reported that sagebrush, *Artemisia tridentata* and rabbitbrush, *Chrysothamnus nauseosus* (Asteraceae) inhabited wild land, adjacent to nectarine orchard, is an important source for emerging western flower thrips, *F. occidentalis* in the spring.

Frankliniella species were collected from numerous uncultivated plants as documented by Chellemi et al. (1994) and Toapanta et al. (1996). Thrips from these hosts can rapidly colonize crops as they begin to flower (Groves et al., 2001). Larvae of *F. occidentalis* live on a number of the ground cover species, suggesting they are appropriate oviposition sites (Pearsall and Myers, 2000). Morishita (2005) collected *F. occidentalis* and *T. tabaci* from the biennial weeds such as chickweed, *Lamium amplexicaule* (Lamiaceae) and henbit, *Stellaria neglecta* (Caryophyllaceae).

Pinent et al. (2006) identified 11 thrips species such as *Smicrothrips particula* (Hood), *Frankliniella rodeos* (Moulton) and *F. gemina* (Bagnall) in the grass tussocks. *Arctotheca calendula* (Asteraceae) appeared to be the most important reservoir host plant of *T. tabaci* in the study of Wilson (1998). Felland et al. (1995) collected western flower thrips, *F. occidentalis* from *Trifolium* spp. (Fabaceae) within the nectarine orchard in Pennsylvania. Yellow tree lupin, *Lupinus arboreus* (Fabaceae), an abundant weed in New Zealand, was hosted by *Thrips obscuratus* (Crawford) (He et al., 2009). Reports of Yudin et al. (1988) indicated that the weeds with flowers attracted thrips more than the same weeds without flowers. Hence, weed species with flowers within and around fields can play the role of reproduction site for thrips.

2.5 Thrips biology

The traits of thrips biology such as their ability to cause direct feeding damage, their tendency to spread widely and their ability to multiply rapidly in favourable conditions give them pest status (Lewis, 1997a). Eggs of thrips in the suborder Terebrantia are smooth-shelled, which are inserted singly into soft tissue of green fruits, flowers and tender leaves by a serrated ovipositor (Lewis, 1973). Tubuliferan thrips attach their eggs, which are larger than those of Terebrantia, onto the surface of the plants. Egg mortality is usually greater in Tubulifera than in Terebrantia. Eggs of thrips are white or yellowish bean-shaped and large in relation to the size of the female body. Individual females lay between 30 and 300 eggs depending on the species and quality of food available (Lewis, 1997a).

Incubation and developmental periods vary with species and environmental conditions (Lublinkhof and Foster, 1977). Eggs hatch after 4-26 days (Lublinkhof and Foster 1977; Lowry et al., 1992 and Murai, 2000). Following hatching, two active feeding larval stages and two inactive non-feeding pupal stages occur with an additional pupal star in the tubuliferan thrips (Lewis, 1997a). Larval development periods range from 2-16 days (Lowry et al., 1992; Murai, 2000). Upon maturity, the late second larval instars finish feeding on the plant and seek protected places to develop into pre-pupal and pupal stages (Lewis, 1973). The duration required for thrips to complete their life cycle from egg to adult stage usually lasts between 10 and 30 days, varying with species, host plant and abiotic factors such as temperature and humidity (Lewis, 1997a). In tropical areas with mean temperature ranging from 25°C to 30°C, the total life cycle of *Ceratothripoides claratris* (Shumsher) is 9 to 15 days (Premachandra et al., 2004).

In warm regions and in greenhouses, up to 12 or 15 generations may be completed each year. In cooler areas, they have only one or two generations, which overwinter as larvae in soil or as adults among dead plant litter, tree bark or crop debris (Lewis, 1997a). Both sexual and parthenogenetic reproductions occur among Thysanoptera. However, reproduction is often parthenogenesis (Lewis, 1997a). Oviparity, ovoviviparity and viviparity are especially common among the mycophagous forms, while arrhenotoky and thelytoky are limited, particularly to phytophagous species. Facultative arrhenotoky is characteristic of species such as *Caliothrips indicus* (Bagnall) and *Chirothrips mexicanus* (Crawford). Thelytoky is typical of *Heliothrips haemorrhoidalis* (Bouche) and *Taeniothrips simplex* (Morison), in which males are rare (Ananthakrishnan, 1993a). *Frankliniella fusca* (tobacco thrips), *F. occidentalis* (western flower thrips) and *Thrips tabaci* (onion thrips) are capable of reproducing by means of both sexual reproduction and parthenogenesis (Higgins and Myers 1992; Lowry et al., 1992).

2.6. Thrips species infesting mango flowers and their damage

The most destructive thrips species are flower thrips primarily species of *Thrips* and *Frankliniella* (Mound, 1997). Since flower thrips feed on pollen, they gain high fecundity and longevity (Tsai et al., 1996). Several thrips species were found to be pests of mango flowers. A survey of the literature indicates that yellow flower thrips, *Frankliniella schultzei* (Trybom), banana flower thrips, *Thrips hawaiiensis* (Morgan), plague thrips, *Thrips imaginis* (Bagnall), Australian tropical flower thrips, *Thrips unispinus* (Moulton), *Haplothrips* spp., *Thrips colouratus* (Schmutz) and chilli thrips, *Scirtothrips dorsalis* (Hood) were found to attack mango inflorescences (Pena et al., 2002; Chin et al., 2006).

Western flower thrips, *Frankliniella occidentalis* (Pergande), *Thrips acaciae* (Trybom), *Thrips tenellus* (Trybom) and South African citrus thrips, *Scirtothrips aurantii* (Faure) infested mango panicles in South Africa (Groves et al., 2001). Florida flower thrips, *Frankliniella bispinosa* (Morgan) and *F. kelliae* (Sakimura) were the most frequently observed pests on mango flowers in Florida (Pena et al., 1998). Blossom thrips, *Megalurothrips distalis* (Karny) and melon thrips, *Thrips palmi* (Karny) were reported as important pests of mango flowers in India (Ramasubbarao and Thammiraju, 1994; Pena et al., 2002). The Mediterranean mango thrips, *Scirtothrips mangiferae* (Priesner) together with the western flower thrips, *Frankliniella occidentalis* occurred on mango in Israel (Wysoki, 1999). *Frankliniella cubensis* (Hood) attacked mango flowers in Costa Rica (Pena et al., 2002).

Thrips locate host plants using colour, shape, size and volatiles associated with them (Terry, 1997). Thrips larvae do more damage compared to adults due to their larger numbers, low mobility and gregarious feeding. Thrips adults and larvae puncture plant cells by their solitary mandible and contents are emptied into the feeding channel formed by the pair of maxillary stylets. Salivary pump injects saliva into plant through the same channel. Sensory structures in the labral pads are involved in host selection and feeding site selection (Ananthakrishnan, 1993a; Mound, 2005). Larval and adult thrips feed within flowers on pollen and cell sap and adults oviposit in the panicles causing retardation of growth, destruction of buds and flowers, panicle discolouration, reduction in vigour of the panicles and ultimately loss of fruit setting (North and Shelton, 1986a; Higgins, 1992; Pena et al., 2002 and Hollingsworth, 2003).

Thrips cause considerable damages to commercial crops through direct feeding on marketable produce or as occasional vectors of plant pathogens. Transmission of plant viruses inducing indirect plant damage poses more serious problems than the direct plant damage (Jones, 2005). Feeding of adults and larvae on mango leaves results in the formation of silvery patches that turn brownish as tissues dry up beneath the epidermis and eventually induces premature leaf fall (Lewis, 1973). Thrips also feed and oviposit on the pericarp of the fruits that cause bronzing of the fruit surface (Figure 2.4) and severe infestations often result in the cracking of the fruit skin. These cosmetic injuries reduce the economic value of mango fruits and their marketability (Grove et al., 2000; Nault et al., 2003).

A **B**

Figure 2.4 Feeding damage caused by thrips on mango fruit (A) and leaves (B).

2.7 Various sampling methods for collecting thrips in the field

Thrips pose special sampling problems due to their small size compared to other insects inhabiting plant (Southwood, 1978). Examining between fruits is a simple technique for monitoring the populations of *Heliothrips haemorrhoidalis* (Bouche) and *Selenothrips rubrocinctus* (Giard) in South African avocado orchards, as these pests prefer to feed between fruits (Dennill and Erasmus, 1991). Simple heated funnels placed in an incubator at 43-52°C (Lewis, 1997c) and a simple Berlese funnel with a 40 W bulb (Shelton and North, 1986) are effective for separating adults and larvae inhabiting leaf sheaths or deep inside buds or compact inflorescences, but the immobile pupal stages are not removed and larvae are partially extracted by this method.

The most commonly used methods to estimate the population density of thrips in fields are shaking or tapping inflorescences over a tray (Grove et al., 2000; Pena et al., 2002 and Duchovskiene, 2006), that is widely used on small trees and bushes (Lewis, 1997c) and washing off the plant materials using 70% ethanol (Suwanbutr et al., 1992; Song, 2001; Reitz, 2002 and Seal et al., 2006b). Earlier, Lewis (1973) introduced several sampling methods for estimating thrips population on plants: (1) sweeping, which is useful for rapid population assessment, but not reliable for estimating the size of population, (2) beating and shaking method and (3) collection of vegetation for subsequent extraction of thrips by washing method. Southwood (1978) employed both the washing and the tapping methods in his assessments of thrips population. There is a large variability between samples in sweeping method. Sweeping for *Megalurothrips sjostedti* (Trybom) on cowpea was twice more expensive and three times more reliable than shaking plants (Salifu and Singh, 1987). In a comparison of suction sampling and sweeping in cereal, a sweeping net caught approximately 18 to 25 times more thrips per unit area than suction samplers, with low efficient collection of thrips concealed in plant crevices in both methods (Lewis, 1997c).

The simplest and quickest method of thrips detection was brushing a moistened palm of the hand across the rice leaves according to Chiang (1977). Irwin et al. (1979) washed soybean leaves in detergent and sieved to remove *Frankliniella tritici* (Fitch) and *Neohydatothrips variabilis* (Beach) in soybean fields. More vigorous shaking in ethanol or detergent solution is necessary for more pubescent and wrinkled leaves, blossoms or buds (Lewis, 1997c). Shipp and Zariffa (1991) obtained more satisfactory result, when they washed leaves and fruits of sweet peppers in detergent (0.1% Triton) compared to ethanol.

Coloured sticky traps in horizontal and vertical positions are popularly used in fields to study the early presence, degree of infestation and flight behaviour of thrips (Puche et al., 1995; Lewis, 1997c; Grove et al., 2000; Pearsall and Myers, 2001; Casey and Parrella, 2002; Nault et al., 2003 and Pizzol et al., 2010). The size of sticky trap depends on the expected thrips density and the frequency of inspection. In case of abundant thrips, a sticky surface of 100 cm^2 is sufficient for daily inspection (Chen et al., 2006). Trap shape can influence trap catches. Cylindrical and cup traps caught more *Frankliniella tritici* (Fitch) per square centimetre than flat traps in staked tomato fields, but it was not true for *F. fusca* (Hinds) and *F. occidentalis* (Pergande) (Cho et al., 1995a). In contrast, Vernon and Gillespie (1995) reported that trap colour was more important than trap shape in catches of *F. occidentalis*.

Using transparent or pale brown traps enables thrips to be recognized easily (Lewis, 1997c). Polyphagous thrips respond to yellow, blue and white with low ultraviolet content and these colours can be used to increase sticky trap catches 10 to 100-fold (Lewis, 1961). However, grass dwellers are less influenced by colour (Lewis, 1997c). Blue sticky trap has been used to catch *Frankliniella intonsa* (Trybom) (Murai, 1988), blue or white for *Thrips palmi* (Karny) (Kitakata and Yoshida, 1982), white for *Megalurothrips sjostedti* (Trybom) (Salifu and Singh, 1987), *Thrips imaginis* (Bagnall) (Kirk, 1987), *Frankliniella orizabensis* and *F. occidentalis* (Pergande) (Hoddle et al., 2002), white or yellow for *Thrips obscuratus* (Crawford) (Teulon and Penman, 1992), *Scirtothrips dorsalis* (Hood) (Grout et al., 1986) and *S. perseae* (Hoddle et al., 2002), green for *Frankliniella fusca* (Hinds), *F. tritici* (Fitch) and *Neohydatothrips variabilis* (Beach) (Irwin et al., 1979).

The sampling technique that estimates the insect density should consider precision, cost and statistical distribution of the data (Schuster, 1998). Comparison of the efficiency of several sampling methods for *Megalurothrips sjostedti* (Trybom) on cowpea was conducted by Salifu and Singh (1987). The sampling techniques were: (1) dipping flowers into ethanol for later counting, (2) shaking plants on gridded wooden plate covered with sticky polythene and (3) sweeping with a 30 cm diameter oval nylon net. Of these sampling methods, shaking method was the least expensive and the most precise method, which was recommended for rapid estimation of thrips density on cowpea. However, it was difficult to estimate absolute count of thrips population using this method and washing method was the only technique, which satisfactorily recovered larvae. Hosney (1964) demonstrated that shaking cotton plants estimated population of *Thrips tabaci* adults as accurate as the removal and washing off whole plants.

Beating of buds was an unreliable method for thrips sampling, whereas collecting buds and counting the thrips in the laboratory was the best method for estimating *F. occidentalis* in nectarine buds (Pearsall and Myers, 2000). According to Lewis (1973), beating method is easily carried out, but part of the population may remain in the plant. Parajulee et al. (2006) reported no difference in the number of adult western flower thrips, *F. schultzei* detected by the washing technique and the visual method, although more larvae were collected by the former method.

2.8 Mango pollinators

Pollinators and pollination are important for maintaining the wild plant communities and agricultural productivity (Kevan, 1999; Ashman et al., 2004 and Klein et al., 2007). Although some plants are self-pollinated or wind-pollinated, most flowering plants require help from pollinators to improve fruit and seed production (Thapa, 2006). Of the total pollination activities, over 80% is performed by insects (Robinson and Morse, 1989). Any organism that lands on the mango flower likely contributes to pollination and it could increase yields of mango (Free and Williams, 1976). Excluding all the insects from the mango panicles and bagging panicles resulted in zero fruit setting (Bhatia et al., 1995). Pollination program of mass rearing