Collecting and Sampling Methods for thrips

Chapter 13

Collecting and Sampling Methods for Thrips

E. A. Silva

Instituto Federal de Educação, Ciência e Tecnologia Goiano, Campus Urutaí, Rodovia Geraldo Silva Nascimento Km 2,5; CEP 75790-000, Urutaí, Goiás, Brasil. Previously at the Universidade do Estado de Mato Grosso, Rua Prof. Dr. Renato Figueiro Varella s/n, CEP: 78690-000, Nova Xavantina, Mato Grosso, Brazil.

e-mail: estevaokienzan@gmail.com

E. F. B. Lima

Universidade Federal do Piauí, Campus Amílcar Ferreira Sobral – CAFS, BR 343, Km 3.5, CEP: 64808-605, Meladão, Floriano, PI, Brazil.

e-mail: efblima@ufpi.edu.br

A. G. Lafuente

Earth and Life Institute – ELIB, Université catholique de Louvain, 4-5 Croix du Sud 1348 Louvain La Neuve, Belgique.

e-mail: arturo.goldaracena@uclouvain.be

R. Marullo

Dipartimento di Agraria - Università degli Studi Mediterranea di Reggio Calabria; Località Feo di Vito, 89122 Reggio Calabria (RC), Italy.

e-mail: rmarullo@unirc.it

Abstract Thrips (order Thysanoptera) are best known for the economic damage they cause in several crops. The use of appropriate sampling methods can help anticipate potential risks to plants (especially crops and other economic important plants) and to control thrips populations after outbreaks. We reviewed widely used methods to sample thrips and provide the main characteristics of each method. We came across twenty that have been developed and constantly updated to sample thrips and obtain the best estimates of their populations. The most common were binomial sampling, direct counts, beating and sticky traps. All these methods have advantages and disadvantages, and the choice of which to use may depend on the objectives of the sampling (e.g. to confirm the presence of thrips, to identify their richness or to infer the damage to plants), personnel, budget available, time, species of thrips and characteristics of the target crop. Recognized pest species in the genera *Frankliniella* and *Thrips* are consistently sampled using different techniques, and this permits prediction of potential damage to crops due to the presence of these insects. Trustworthy sampling and monitoring protocols, established through detailed observations and previous experience working with thrips are vital for management decisions, because even at very low densities, thrips can cause considerable yield losses.

Keywords *Frankliniella*, crop pests, economic damage, monitoring, sticky traps

13.1 What are Thrips?

Thrips are tiny (generally < 2 mm in length) and furtive insects which occur all over the world, except on the poles. These insects are opportunistic and explore intermittently occurring environments, such as blooming flowers and expanding leaves. Most thrips are *r*-selected and usually possess few natural enemies (Funderburk et al. 2000). Thrips exhibit varied lifestyles (Morse and Hoddle 2006) - as predators, facultative predators, leafhopper ectoparasites, phytophagous, gallers and fungus feeders (Mound and Marullo 1996; Mound 2005). In some cases, a single species can occupy distinct niches, such as the *Pseudophilothrips* that inhabits neotropical Malpighiaceae. Both adults and larvae feed on all aerial plant parts, and are found on leaf buds, leaves, flower buds, flowers and fruits (Alves-Silva and Del-Claro 2016).

Although thrips exhibit such diverse habits, the Thysanoptera are best known for the economic damage they cause in several crops. In phytophagous species, the thrips puncture the epidermis of plant tissues to feed on sap and cell contents; as a result, plant tissues turn brownish and blackish and these necrosis marks are evidence of feeding by thrips. Thrips can be taken to long distances, either by wind and by the introduction of infested plant (Mound 1997).Only about 2% of the described thrips species are recorded as pests (Moritz et al. 2004), and studies in general focus on these pest species. Thus, our knowledge of sampling, monitoring, identification and life stories are widely known for these species, in comparison to non-pest species.

13.2 Objective of the Chapter

This chapter aims to cover the main sampling methods for thrips and the need for both detailed field studies and meticulous monitoring. We reviewed widely used methods for sampling thrips and we provide the main characteristics of each. Our research covers pest species only, since most sampling techniques have been developed to monitoring this group, especially species in the genera *Frankliniella* and *Thrips*. A detailed understanding of the advantages (or the lack thereof) of each sampling technique not only helps to prevent potential risks to crops, but also to control thrips populations after outbreaks.

13.3 Why Sample Pest Species?

Sampling of pest thrips is the first and most important step to prevent, anticipate and monitor potential damaging species. Samplings also allow identification of the main characteristics that must be taken into consideration when performing actions to control thrips, such as: *(i)*

functional groups – fruit, flower and leaf feeders; *(ii) immigrant or exotic species* - permitting a rapid evaluation of invasive species that might become pests, so actions can be anticipated to prevent a burst of populations (Morse and Hoddle 2006); (iii) *host exploitation* - niche overlap among species, temporal and spatial distribution in plants (Lee and Wen 1982; Tappan 1986).

13.4 Economic Importance of Thrips

Despite early conviction that thrips were small and were not a concern in some crops (e.g., soybean – Irwin and Yeargan 1980), current research shows that even at exceptionally low densities thrips can cause considerable yield losses. Regardless of the use of biological control agents, (expensive and environmentally risky) pesticides and integrated pest management (IPM) programs (Helyer and Brobin 1992), thrips have been a source of damage to crops causing severe losses in yield (Welter et al. 1990; Walsh et al. 2012). Their agricultural importance involves direct damage to plant tissues during oviposition and feeding and/or transmission of phytopathogenic agents, especially viruses (Lewis 1997; Pereira et al. 2017). The role and ability of thrips to vector a wide diversity of viruses (currently labelled as orthotospoviruses) is often the most serious damage from thrips, especially those in the family Thripidae (Jones 2005).

Thrips feeding on plants can damage all above ground parts, such as fruits, leaves, and shoots. The insects can also cause serious injury in young plants, which seem to be more susceptible to thrips attack (Fig. 13.1) (Dreistadt 2001).

13.5 Literature Survey

We conducted an extensive survey of the literature to investigate the methods that have been used so far to collect thrips, which crops were targeted for thrips sampling, and the thrips species that were commonly sampled. The search was made using Google Scholar (as it combines several databases and papers from many publishers), with the words "*thrips sampling*" and "*thrips monitoring*" and included papers published until December 2017. The reference lists at the end of papers was also used as a source of information to enrich our survey. Each paper was carefully read, and the pertinent information was retrieved and systematically organized. This resulted in 64 published papers in which authors had studied, compared and/or developed sampling techniques for thrips.

The samplings included thrips in fields (containing plants of many species at once) and in over 39 specific plants. The most important plants, in terms of associated thrips, are shown

in Fig. 13.2, which also indicates the richness of thrips, especially in the genera *Frankliniella* and *Thrips* associate with plant species. Species in these two genera were consistently sampled and monitored (Fig. 13.3) (according to the data obtained from the literature) and the richness of *Frankliniella* outnumbered the other genera. Together, both *Frankliniella occidentalis* and *Thrips tabaci* were found to be pervasive in the investigations to sample and monitor thrips (Fig. 13.4).

Methods to sample thrips were tested in 20 different countries (Argentina, Brazil, Canada, Caribbean, France, Hungary, Iraq, Kenya, Korea, Malaysia, Netherlands, Nigeria, New Zealand, South Africa, Spain, Switzerland, Taiwan, Turkey, United Kingdom and USA), and sometimes a single study involved sampling in more than one country (e.g., Abdullah et al. 2015). The USA was by far the most common country where thrips were sampled (42% of occurrences), followed by Canada (7%), Brazil (6%) and France (6%).

Several pest species, such as western flower thrips (*Frankliniella occidentalis*), banded greenhouse thrips (*Hercinothrips femoralis*), gladiolus thrips (*Taeniothrips simplex*), greenhouse thrips (*Heliothrips haemorrhoidalis*) and onion thrips (*Thrips tabaci*) are relatively common species in nursery crops in Europe and America (Hoodle et al. 2008). Major pest species in the genus *Frankliniella* and *Thrips*, which were fairly common in our literature survey, are pest in dozens of economic important crops (e.g., rice [Cavalleri et al. 2010], tomato [Cho et al. 1995], potato [Cho et al. 2000], peach, strawberry, persimmon, grape [Pinent et al. 2007, 2008]), and can attack practically all above-ground parts of plants (Tappan 1986). *Thrips tabaci* is a major pest of onion and garlic; *T. palmi* attacks various vegetables and fruit trees; *Frankliniella occidentalis* has great importance in horticultural and ornamental plants; *F. schultzei* is highly polyphagous (Lewis 1997). Viruses transmitted by thrips have been recorded in over 1000 plant species (Riley et al. 2011).

Our data shows that thrips attack economically important crops that are grown all over the world, and the most important pests are *Frankliniella* and *Thrips*. The development of control measures have thus focused on these particular thrips species, as they attack a variety of crops.

13.6 Sampling Methods for Thrips

Thrips populations are mainly found in the soil (including litter), vegetation or air. Several methods for sampling have accordingly been developed, then compared and consistently used for sampling thrips in the field and to estimate their richness, density, economic injury level

(the lowest population of thrips that can yet cause damage to plants) and economic threshold (a density below the economic injury level) (Nault and Shelton 2010).

The sampling of thrips has been reviewed and has evolved to optimize the capture and counting of these insects in the field (Pelley 1942; Lewis 1959; Powell and Landis 1965; Irwin and Yeargan 1980; Lewis 1997; Rieske and Raffa 2003; Reisig et al. 2010). Nevertheless, even nowadays, with great advances in the knowledge of thrips biology and ecology, many scientists still face problems in dealing with accurate methods to monitor thrips populations in the field (Pearsall and Myers 2000). In applied entomology, absolute or relative surveys of pest thrips are described for several crops, although the action levels (when available) for implementing control tactics may differ in distinct areas of the globe.

Sampling and knowledge of the species (i.e., which and where) are a first step to establishing the most appropriate strategy for controlling thrips and preventing further economic cropping losses. Trustworthy sampling and monitoring protocols, established through detailed observations (and even experimentation), and previous experience in working with thrips, are vital for management decisions (Nault and Shelton 2010). For instance, the presence of some species of *Frankliniella* (e.g. *occidentalis*, *schultzei*) above a determined threshold can be seen as an early warning sign, because of the potential of some thrips to transmit orthotospoviruses (Cho et al. 1995; Riley et al. 2011).

The success of any sampling strategy depends upon knowledge of the distribution of thrips in time and space (Cho et al. 1995). Since each species presents its own behavior in plant occupation (e.g., leaves, flowers, fruits), feeding preferences (pollen, leaf sap, cannibalism) (Mound and Marullo 1996) and biology (Reisig et al. 2010), this imposes a difficulty in establishing a single sampling procedure for all thrips which can be found even in a single plant species (Irwin and Yeargan 1980). In crops where more than one species of pest thrips occurs concurrently (Fig. 13.2), it might be necessary to perform several samplings and compare different methods to make a good estimation of thrips richness (Cho et al. 1995). Economic thresholds must be established for pest species, to anticipate whether thrips densities are in a level that incurs significant yield losses (Mcintyre-Allen et al. 2005; Nault and Shelton 2010). This is a key step for IPMs and helps farmers to take control measures (Abdullah et al. 2015; Pereira et al. 2017).

Ideally, the sampling plans for thrips should follow important phases, including the economic injury levels associated with the pest, the control of costs and the validation of the sampling. A complete step-by-step procedure is given by Pereira et al. (2017). These authors determined the control costs by surveying the pesticides and equipment used for spraying

watermelons (~US$ 80,00 ha^{-1}); inspected plants in the field to establish a relationship between thrips densities and yield losses (t ha^{-1}; R^2 = 0.97); investigated the crop production value (US$ from 62.5 to 218.75 t^{-1}); analyzed the economic loss caused by thrips (36%); the economic injury level (0.02 to 0.09 insects per sample); estimated the costs of controlling thrips (2% of the production value) and provided information about the decision to control thrips based on plant phenological stage.

13.7 Sampling Plans for Thrips - Parameters

A total of 20 sampling methods for thrips were recorded in our literature survey, and the main characteristics of each are described below. The samplings can be classified according to distinct parameters (Table 13.1). Two types of sampling are (con)currently used to monitor thrips, the relative, when only a proportion of thrips infesting the plants are inferred; and the absolute, when all thrips per plant are counted. An early classification of samplings is given by Irwin and Yeargan (1980), who classified samplings as either delayed (i.e., removal of plant parts in the field and processing in the laboratory) or direct counting (counting thrips directly in the field) of thrips infesting soybean.

Methods can be destructive (e.g., delayed counting) or non-destructive (e.g., direct counting) (Pearsall and Myers 2000; Muvea et al. 2014). In the former, plant structures are collected or cut-off, whereas in the latter this is not necessary. Sampling plans can also be selective or non-selective (Lewis 1959). For instance, the use of sticky traps and odors is a selective method, as the response of thrips to colors and odors are species-specific. The beating method is non-specific as it captures all thrips species foraging on a plant structure.

Many of the methods used to sample thrips were originally created for other insects (e.g. pitfalls, sweep nets, beating, light traps) and guidelines have evolved to account for most thrips exceptionalities (phenotypic variation, life stages, within-plant distribution) (Chu et al. 2006; Fedor et al. 2007; Reisig et al. 2010). The characteristics of each method are summarized below and are a compilation of the sampling strategies used and developed throughout the years to provide the best estimate of thrips in several distinct scenarios.

13.8 Absolute Sampling

Absolute counting involves the extraction of the whole plant from the soil and the counting of all thrips (Joost and Riley 2004; Liu and Chu 2004). It is made with low-sized crops or seedlings (e.g. lettuce, onion) (Palumbo et al. 2003). Bagged plants are filled with ethanol and shaken to

detach thrips from the plant parts. The ethanol is then filtered and thrips are counted. Freezing plants to immobilize thrips, instead of the use of bags with alcohol, is also described (Al-karboli and Al-Anbaki 2014). Plants can also be washed off in the laboratory to remove the thrips (Liu and Chu 2004). The absolute method can sometimes be used as a reference for comparisons with other sampling techniques (Joost and Riley 2004; Aliakbarpour and Rawi 2010). Instead of collecting the whole plant, researchers can also collect a given plant structure, take it to the laboratory and then estimate thrips density in that plant structure (Aliakbarpour and Rawi 2010).

13.9 Relative Samplings

Binomial sampling This technique is not based on the complete enumeration of thrips in plants or plant structures, but rather on the presence or absence of these insects. This method is preferred over the others when thrips are difficult to count (Ugine et al. 2011). Action is undertaken when the proportion of plants with thrips exceeds a given threshold (e.g. 50%) (Cho et al. 1995 and references; Laudonia et al. 2000). Further samples of the incidence of thrips can be made to record their density (Navas et al. 1994).

Direct counts Plants are carefully inspected and thrips abundance is estimated directly on the above-ground structures; adults, and sometimes larvae, are recorded (Palumbo et al. 2003). This is acknowledged as the best method to assess the density of *Frankliniella schultzei* in watermelon (Pereira et al. 2017).

Beating Plant structures are shaken over a sheet of white paper/plastic (or a counting board - Powell and Landis 1965), which may be moist to avoid thrips from flying. In a variation of the method, plant structures are beat vigorously against a screened pan for a predetermined time, and the dislodged thrips are retained via a sticky trap located below the pan (Palumbo et al. 2003). The plant part can also be shaken inside a plastic cup (Reisig et al. 2010; Joost and Riley 2004). Beating permits the collection/counting of adults and larvae (Powell and Landis 1965). Thrips can be collected with a fine brush and placed in vials for further identification. This method is used in plants where thrips are abundant and rich, and it permits the identification of all thrips species infesting plants, as well the temporal monitoring of their populations. This procedure was used to monitor thrips in sweet pepper in Hungary and the results revealed the occurrence of 21 thrips species infesting greenhouse crops. It was also possible with this method to unravel different temporal variations of thrips species and their rise and collapse in the course of years (Aliakbarpour and Rawi 2010; Orosz et al. 2017).

Sticky traps/cards/boards Sheets (e.g., 10 cm × 25 cm – Abdullah et al. 2015; 13 x 10 cm - Demirel and Yildirin 2008; 16 x 19.5 – Coli et al. 1992) with a sticky substance and different colors (yellow, red, blue, black – Liu and Chu 2004), depending on the thrips species to be sampled, are placed near or above plants and flying thrips are intercepted by these traps. Sheets are gridded with 1 cm^2 squares, which are used as a proxy to estimate thrips numbers. This is also used to investigate the flight activity of thrips (Aliakbarpour and Rawi 2010). Counting can begin after a predetermined period (Palumbo et al. 2003). This method takes advantage of the high mobility of thrips species, especially the pest species. Traps are often replaced to record the abundance of thrips along the cropping period; thrips are removed from the sticky cards with kerosene and collected with a fine brush (Muvea et al. 2014). This is one of the most common monitoring methods to sample economically important thrips (Bergant et al. 2005). It is commercially available (Fig. 13.5).

Plant part extraction Plant structures (leaves, inflorescences, branches) are cut off and placed in vials that can be empty or contain a preserving solution. When empty vials are used, this method permits thrips to be counted in-vivo in the laboratory. Thrips usually detach from the plant structures and wander on the vial, from where they can be collected with a fine brush. This method is the most appropriate for observations of thrips behavior in the laboratory, as it conserves the original plant structure and the associated thrips. If, instead, the plant structure is put in a vial containing a preserving solution (Aliakbarpour and Rawi 2010), it can be poured into a Petri dish or filtered using a fine cloth. In the case of flowers, dissection can be necessary to extract thrips that become stuck inside the corolla (Cho et al. 1995; Moreira et al. 2017; Orosz et al. 2017). A variation of the method includes positioning the plant structure over a table and brushing it to remove thrips (e.g., potato plants - Powell and Landis 1965). A pole-pruner or a tree-climber can be used to collect samples on tall plants (Werner et al. 2004).

Washing off the plant part In the field, a plant structure is submerged into a jar containing ethanol and shaken; the ethanol is then filtered using a fine mesh and the thrips are counted (Aliakbarpour and Rawi 2010).

Odor baits and olfactory response Chemical attractants are spread in sticky cards with the function of luring thrips (Muvea et al. 2014). They are commercially available (Abdullah et al. 2015). A variation consists of volatile compounds mixed with water and placed in plastic containers (0.5 l) suspended on wooden stakes (Rieske and Raffa 2003).

LEDs in sticky traps Evaluated by Chen et al. (2004) as a monitoring method for western flower thrips. Light-emitting diodes (LEDs) are attached to sticky cards.

Caged sticky cards Cards are covered with a nylon mesh screen to prevent the capture of large insects, which might saturate the sticky cards and prevent the capture of thrips (Chen et al. 2004).

Immobilization with CO_2 Plant parts containing thrips are enclosed in a plastic bag and carbon dioxide is released inside the bag. After a period of 30 second CO_2 incapacitates the thrips, which fall to the bottom of the plastic bag and are then taken to the laboratory (Aliakbarpour and Rawi 2010).

Light Traps As presented by Fedor et al. (2007), the light trap makes use of the positive phototaxy and negative geotropism of bark-dwelling insects. The trap consists of an inverted funnel that is fixed to a PVC tube containing a conserving solution. This PVC tube acts as a collecting vessel. Above, and involving the PVC tube, another tube is placed to prevent the escape of insects. The trap is wired to the bark of trees.

Tanglefooted Tile This method is described by Irwin and Yeargan (1980) to collect flying thrips, but it seems to be more appropriate to sampling aphids (Irwin 1980). The method comprises a horizontally oriented ceramic tile covered in a thin layer of Tanglefoot (the same wax used in ant-exclusion experiments) placed at canopy level of soybeans. Thrips attached to the wax are removed with acetone.

Aspirator or Suction Traps Sucks up thrips from plants (Joost and Riley 2004).

Electric Vacuum Device An electric suction tube is used to collect thrips (Joost and Riley 2004). D-vacuum insect nets are a variation (Rhodes and Morse 1989).

Sweep Nets A funneled net of approximately 38 cm diameter radius is swung from side to side in a 180-degree arc (Reisig et al. 2010).

Ground Traps, Pupation Papers or Carton Trap Sticky traps are placed under plants to collect pupating larvae that drop off plants to pupate in the soil (Tanigoshi and Moreno 1981; Rhodes and Morse 1989). A variation consists of folded papers that are distributed among horizontal twigs, above the ground, inside the plant canopy; it captures immature thrips (Grout et al. 1986; Rhodes and Morse 1989).

Shotgun Used, and not recommended, for sampling thrips by Werner et al. (2004). It was designed to sample branches from tall trees.

Flotation Used to sample thrips from soil and litter; after filtering the soil using different meshes, heptane is used to float thrips (Parker et al. 1992).

13.10 Comments on Some Methods

All these methods have advantages and disadvantages and the choice of which to use may depend on the objectives of the sampling (e.g., to be sure of the presence of thrips, to identify the biodiversity of thrips, to identify damage to plants), costs and time involved. The relationship between sampling method and sampling parameters can aid in the choice of the most appropriate method to sample thrips (Table 2). Some methods might be impractical (use of shotgun); costly (immobilization with CO_2) or time demanding (absolute counting), and researchers must thus find a balance between sampling, parameters and costs.

A comparison of three relative methods (direct counts, beating tray and sticky traps) revealed that absolute counting was by far the best for estimating thrips populations in lettuce; the other methods either failed to make correct estimates of thrips or provided low numbers of thrips larvae. In some occasions, the beat pan yielded comparable results to absolute sampling and could be used as an alternative to such highly invasive methods (Palumbo et al. 2003). Of two sampling methods used in mango orchards, the beating tray and immobilization using CO_2, the latter provided the best estimates of thrips abundance, compared with absolute counting (Aliakbarpour and Rawi 2010). No difference was found in beans between sticky traps, collecting, and tapping leaves and flowers (Muvea et al. 2014); in cotton, the washing technique yielded more thrips in comparison to visual estimation (Parajulee et al. 2006), and in roses the yellow sticky traps were accurate enough to be used in greenhouses (Pizzol et al. 2010).

Absolute sampling demands more effort but is advantageous because the researcher or farmer can be confident that the species sampled are indeed in the study plant, even though some species may be only visitors. Absolute sampling also provides information about immature individuals and brachypterous or apterous specimens that are rarely caught on sticky traps (Reisig et al. 2010). This method may require the removal of the whole plant from the soil/crop, so it cannot be used for large plants. Relative methods infer only a proportion of thrips infesting the plants and thus they should be used with this drawback in mind.

Sticky traps are by far the most widely used method to sample thrips. The colors used to attract thrips species may vary between different crops, which might be related to the contrast between the crop and trap colors. Although the range of colors varies for each species, growers in agricultural areas prefer to use yellow sticky traps due to their cost-effectiveness, as other pests can also be attracted by this color, including whiteflies and aphids (Lewis 1997). These traps can give a good information about the species composition of a given area but have some disadvantages. Although commonly used, they are affected by wind speeds, and thrips from other areas, carried by the wind, could be collected. Sticky traps also have the disadvantage of damaging thrips when they strongly attach to the trap material, thus jeopardizing their

identification. Sometimes the species collected on cards are not actually associated with the plant from which thrips are being sampled. Cho et al. (1995) tested different colors of sticky traps to sample thrips from tomato fields and noted that *Frankliniella tritici* had been collected in high populations from colored traps, although very few specimens were collected directly from flowers.

The beating method may remove not only thrips, but also other insects from the plant. When made on flowers, beating can cause damage to corollas, loss of pollen and even flower abscission. This method causes disturbance to the plant and to the associated arthropods. Once disturbed, some thrips might simply fly away, and thus this method might underestimate thrips abundance.

Direct counts are widely used in ecological studies, and this seems to be the less invasive method, as it requires neither thrips collection nor plant extraction, so that the system remains relatively undisturbed. This method should be undertaken by an experienced researcher who is able to reliably tell thrips from other insects. Another issue is that this method is not appropriate for sampling thrips in plants that are rich in these insects, as the identification of thrips species in these cases might be difficult. Moreover, tiny thrips larvae cannot be reliably estimated in this method, nor thrips that are highly spatially distributed in the plant, inconspicuous individuals, or those that hide in small cracks. It can therefore eventually underestimate the number of thrips, jeopardize the economic injury level and economic thresholds estimation. This method can also be time-consuming, should large plants and several structures be inspected (Fig. 13.6).

13.11 Relationship Between Sampling Technique and Time

The choice among different sampling techniques must take into account several factors, such as personnel, budget available, time, species of thrips and characteristics of the target crop. For example, in a comparison of the beating tray and flower collection (in vineyards), the latter was the best sampling method, yielding three times more thrips than the former method; however, the costs (14-fold higher) and time (1.4-fold higher) associated with it were considerably elevated. The authors then estimated the most economically effective sampling and concluded that ten inflorescences per hectare were ideal to provide reliable indicators of thrips abundance in vineyards (Moreira et al. 2017). In another study, four sampling methods were evaluated (absolute counting, direct counting, water cups and sticky cards) and the authors found a great difference with regard to the time required for processing (preparation to counting all thrips) the samples. Absolute counting required longer periods of processing,

yielding a 15-fold difference in comparison to direct counting, but was the best sampling technique (Liu and Chu 2004).

Two formulas are usually used in studies that compare sampling techniques and costs of sampling, namely "*Relative variation* (RV)" and "*Relative Net Precision* (RNP)". The former evaluates the precision of a sampling method; values < 25% are most appropriate for general estimates. The latter compares the best sampling efficiency. The higher the *RNP*, the better the sampling efficiency (more details in Pearsall and Myers 2000; Joost and Riley 2004). The formulas are given below:

$$RV = \left(\frac{SEM}{mean}\right).100 \qquad RNP = \left(\frac{1}{RV\,.\,Cs}\right).100$$

where *RV* = relative variation; it is calculated by SEM/mean and is estimated with the number of thrips in each sampling unit. ***Cs*** = costs in hours of labor of collecting and managing a given number of samples.

In staked tomatoes, no difference in time was found for sampling effort regardless of whether 2, 5 or 10 flowers were collected, but the time to process the samples, including the counting and identification of thrips, was significantly different between samples. The sampling of 10 flowers per unit was almost double that of two flowers, but the relationship between cost and sampling efficiency (*Relative Net Precision*), was higher for the 10-unit flower survey (Cho et al. 1995).

13.12 Monitoring Thrips in The Crop

There are no treatment guidelines based on thrips density for most crops. Plants highly susceptible to viruses should be kept virtually free of thrips. Deciding when to treat crops is difficult and subjective because often there is no simple relationship between thrips density and plant damage, and thrips density in traps does not always correlate with thrips density in crops. However, growers who regularly inspect plants and consistently employ well-maintained traps can establish thresholds over the long term by judging the historic monitoring records. Whenever there is evidence of thrips infesting and damaging plants, both adult and larvae can be sampled using any of the methods described here. A rapid assessment could be made by beating or shaking vegetation onto a sheet of paper, and a long estimation could require the use of sticky traps (Broughton and Harrison 2012). The addition of lures baited with aggregation pheromones or kairomones to sticky traps can be used as an addition tool to capture specific

thrips species (Broughton et al. 2015). Plants suspected of being infected by orthotospoviruses can be reliably identified from symptomatic parts sent to a laboratory that tests for plant pathogens. The thrips species can be identified only by an expert taxonomist, because individuals are small, polymorphic and some characters are hard to be seen by naïve taxonomists (Mound 2005).

13.13 Difficulties in Sampling and Identification

To the best of our knowledge it has so far been impossible to devise a standard procedure to sample thrips in all plants. Since thrips are highly abundant in plants, with a great capacity for moving from plant structures, both active and passive flying, and with an overlap of different species in the same individual plant, it is necessary to judge which sampling methodology is the most appropriate in each type of study (Werner et al. 2004). For instance, Nault and Shelton (2010) decided to visually count only thrips larvae in onions, as they claimed that adults moved between plants and plots. Since larvae are more abundant than adults in many cases, are voracious feeders and transmit orthotospoviruses (Navas et al. 1994; Pearsall 2000; Riley et al. 2011; Moreira et al. 2017), this strategy can be worthwhile, depending on the objective.

Sampling plans are not easy to establish. The density of thrips is affected by weather, time, plant phenology and age, the presence of alternative hosts, natural enemies, prey and competitors (Picket et al. 1988; Tamo et al. 1993; Al-karboli and Al-Anbaki 2014; Orosz et al. 2017). Depending on the plant species and time of sampling, larvae can outnumber adults (Werner et al. 2004; Moreira et al. 2017), thus imposing restraints on the type of sampling to be employed, since larvae are wingless and, in most cases, cannot be identified to species.

For most methods, sampling the plant structure on which thrips are most abundant or expected provides maximum efficiency. Thrips are minute and furtive insects, which makes them very difficult to sample and some may be unnoticed at first (Mehle and Trdan 2012). Behaviors such as hiding in small cracks, inside flowers and under leaves are common in several species (Kirk 1984; Del-Claro et al. 1997; Mound and Terry 2001), thus making sampling difficult (Frey et al. 1994; Ugine et al. 2011), or even impractical in relation to time and budget restrictions. For instance, thrips can be very abundant in flowers where they are very active, coming in and out of the corolla frequently, or wandering on the petals; these thrips have a tendency to escape, hide or drop from plants in response to disturbance (Powell and Landis 1965; Alves-Silva and Del-Claro 2016), and thus the mere presence of the researcher can have a big effect, and affect a precise estimation of thrips abundance (Werner et al. 2004; Ugine et al. 2011). A sampling plan must undoubtedly take these considerations into account.

Thrips are not randomly distributed within plants, thus imposing a restriction on the methods that can potentially be used or requiring a preliminary study with observation of the host exploitation by thrips (Navas et al. 1994; Navarro-Campos et al. 2012). A failure to recognize this can result in elevated sampling error, underestimation of the actual density of thrips, and an inability to anticipate which changes in population may cause economic injury (Pearsall and Myers 2000). According to Irwin and Yeargan (1980), as well as thrips characteristics such as the distribution within plants, it is necessary to accurately include the time (period of day, the periodicity of the sampling, phenological events of plants), the sample unit (leaves, flowers, the whole plant) and the number of sample units in a sampling program.

For taxonomic studies involving collections of thrips from plants or wood, active sampling methods are usually the best option. Only in this way will the researcher gather accurate details on the origin of the specimens to be provided as biological data in species descriptions or other publications. A widely used method involves beating leaves, flowers or dead twigs using a wooden stick, and collecting specimens with a soft brush from a plastic tray put under the area.

The identification of male and female thrips can be made only with specimens mounted on slides for microscopic visualization and, depending on the method used, a large quantity of thrips must be required (several methods are reviewed in Mehle and Trdan 2012). For larvae, only the second instar onwards is usually used for thrips species identification (Orosz et al. 2017). This might be a problem for plants that harbor many larvae (Moreira et al. 2017), since identification is imprecise; thus, a plant might sustain many species of thrips, but they cannot be reliably identified from larvae. For a few thrips, identification from first instar larvae is possible (e.g. *Pezothrips kellyanus* (Bagnall)), but even so, raising larvae until the adult stage provides the best accuracy in the identification of thrips (Navarro-Campos et al. 2012). The reliable identification of thrips is necessary whenever a researcher aims to determine actions to control potential pests, because some species, even within the same genus (e.g. *Frankliniella*) are capable of transmitting a virus, whereas other species are not (Navas et al. 1994).

13.14 Comments on Native Species of Brazil

The Brazilian fauna of Thysanoptera comprises over 600 species, representing about 10% of the approximately 6,200 described valid worldwide (Lima 2019; ThripsWiki 2019). This richness makes Brazil as the country with the largest known thrips fauna in the Neotropics (Alves-Silva and Del-Claro 2010; Mound 2014), although the total richness represents less than one third of the estimated (Monteiro and Mound 2012) and comes largely from of studies

conducted in southern and southeastern Brazil. In the Atlantic Forest biome, mostly present in the south and southeast and occupying about 13% of the national territory, there are 433 recorded species. On the other hand, the biomes such as the Amazon and the Cerrado (Brazilian Savanna), mostly present in the Northern and central zones, and occupying around 50% and 25% of the national territory, respectively, account for approximately 100 species recorded each (Lima 2019).

Even with this discrepant scenario, there is a great diversity of habits among Brazilian species. Although the most known thrips are approximately 45 pest species (mostly in the genera *Frankliniella* and *Thrips*), of which seven are reported as *Orthotospovirus* vectors, the majority of Brazil's thrips is composed of fungivorous species that live especially on dry branches or leaves (Monteiro 2002; Lima 2019). In addition to these, there are four species of *Aulacothrips*, the only genus of ectoparasite thrips, that live in association with leafhoppers (Cavalleri and Kaminski 2014); several species of *Scolothrips*, *Karnyothrips*, *Franklinothrips* and *Leptothrips*, generalist predators of small arthropods (Mound and Marullo 1996; Monteiro 2002; Lima 2019); predators in the genus *Mirothrips*, which feed on social wasp eggs (Cavalleri et al. 2013); and pollinators of endangered species such as *Frankliniella gardenia*, who dwells on flowers of *Ocotea porosa* (Lauraceae) (Danieli-Silva and Varassin 2012).

13.15 Conclusion

Thrips, notably the pest species, are highly polyphagous and can attack several crop species. Our survey shows that dozens of tools have been developed to monitor thrips, but actions to control their populations depend on reliable taxonomy, since even within sympatric thrips pest species, differences in niches, behavior and resistance to pesticides must be considered in order to achieve the goal of controlling their populations. Most pest thrips that occur in crops, and are consequently sampled, belong to the genera *Frankliniella* and *Thrips*, and in fact these are the most studied genera all over the world when it comes to thrips. We note that most studies have been conducted in the USA, and thus the results of the methods to sample thrips are geographically biased. Thrips exhibit a series of interactions with the environment and other insects (prey/food, competitors, predators), and samplings in different parts of the world might provide very different results in terms of species sampled and appropriate methods with which to estimate the density of thrips.

Acknowledgements

We are deeply grateful for the invitation to write this chapter and contribute with the study of thrips. Our most sincere acknowledgements go to editors (J. C. Santos and G. W. Fernandes), to professor Laurence Mound, for his kindness and attention to the study of thrips worldwide. EAS also thanks the CNPq and PELD (Programa Ecológico de Longa Duração) for funding and to professor K. Del-Claro to introduce him to the study of thrips ecology when he wanted to study spiders.

References

Abdullah ZS, Greenfield BPJ, Ficken KJ, et al (2015) A new attractant for monitoring western flower thrips, *Frankliniella occidentalis* in protected crops. Springerplus 4:89. doi: 10.1186/s40064-015-0864-3

Aliakbarpour H, Rawi CSM (2010) Diurnal activity of four species of thrips (Thysanoptera: Thripidae) and efficiencies of three nondestructive sampling techniques for thrips in mango inflorescences. J Econ Entomol 103:631–640. doi: 10.1603/EC09167

Al-Karboli HH, Al-Anbaki HA (2014) Efficacy of tow sampling methods for monitoring, control and estimating seasonal abundance of onion thrips, *Thrips tabaci* Lindeman (Thripidae: Thysanoptera) on onion in Iraq. Int J Agric Technol 10:243–251.

Alves-Silva E, Del-Claro K (2010) Thrips in the Neotropics: what do we know so far? Trends Entomol 6: 77–88.

Alves-Silva E, Del-Claro K (2016) On the inability of ants to protect their plant partners and the effect of herbivores on different stages of plant reproduction. Austral Ecol 41:263–272. doi: 10.1111/aec.12307

Bergant K, Trdan S, Žnidarčič D, et al (2005) Impact of climate change on developmental dynamics of *Thrips tabaci* (Thysanoptera: Thripidae): can it be quantified? Environ Entomol 34:755–766. doi: 10.1603/0046-225X-34.4.755

Broughton S, Cousins DA, Rahman T (2015) Evaluation of semiochemicals for their potential application in mass trapping of *Frankliniella occidentalis* (Pergande) in roses. Crop Prot 67:130–135. doi: 10.1016/j.cropro.2014.10.011

Broughton S, Harrison J (2012) Evaluation of monitoring methods for thrips and the effect of trap colour and semiochemicals on sticky trap capture of thrips (Thysanoptera) and beneficial insects (Syrphidae, Hemerobiidae) in deciduous fruit trees in Western Australia. Crop Prot 42:156–163. doi: 10.1016/j.cropro.2012.05.004

Cavalleri A, Kaminski LA (2014) Two new ectoparasitic species of *Aulacothrips* Hood, 1952 (Thysanoptera: Heterothripidae) associated with ant-tended treehoppers (Hemiptera). Syst Parasitol 89:271–278. doi: 10.1007/s11230-014-9526-z

Cavalleri A, Mendonça Jr M S, Rodrigues ENL (2010) Thrips species (Thysanoptera, Terebrantia) inhabiting irrigated rice and surrounding habitats in Cachoeirinha, state of Rio Grande do Sul, Brazil. Rev Bras Entomol 54:501–504. doi: 10.1590/S0085-56262010000300023

Cavalleri A, de Souza AR, Prezoto F, Mound LA (2013) Egg predation within the nests of social wasps: a new genus and species of Phlaeothripidae, and evolutionary consequences of Thysanoptera invasive behaviour. Biol J Linn Soc 109:332–341. doi: 10.1111/bij.12057

Chen T-Y, Chu C-C, Fitzgerald G, et al (2004) Trap evaluations for thrips (Thysanoptera: Thripidae) and hoverflies (Diptera: Syrphidae). Environ Entomol 33:1416–1420. doi: 10.1603/0046-225X-33.5.1416

Cho K, Eckel CS, Walgenbach JF, Kennedy GG (1995) Spatial distribution and sampling procedures for *Frankiniella* spp. (Thysanoptera: Thripidae) in staked tomato. J Econ Entomol 88:1658–1665. doi: 10.1093/jee/88.6.1658

Cho K, Kang SH, Lee GS (2000) Spatial distribution and sampling plans for *Thrips palmi* (Thysanoptera: Thripidae) infesting fall potato in Korea. J Econ Entomol 93:503–510. doi: 10.1603/0022-0493-93.2.503

Chu C-C, Ciomperlik MA, Chang N-T, et al (2006) Developing and evaluating traps for monitoring *Scirtothrips dorsalis* (Thysanoptera: Thripidae). Florida Entomol 89:47–55. doi: 10.1653/0015-4040(2006)89[47:daetfm]2.0.co;2

Coli WM, Hollingsworth CS, Maier CT (1992) Traps for monitoring pear thrips (Thysanoptera: Thripidae) in maple stands and apple orchards. J Econ Entomol 85:2258–2262. doi: 10.1093/jee/85.6.2258

Danieli-Silva A, Varassin IG (2013) Breeding system and thrips (Thysanoptera) pollination in the endangered tree *Ocotea porosa* (Lauraceae): implications for conservation. Plant Species Biol 28:31–40. doi: 10.1111/j.1442-1984.2011.00354.x

Del-Claro K, Marullo R, Mound LA (1997) A new Brazilian species of *Heterothrips* (Insecta: Thysanoptera) co-existing with ants in the flowers of *Peixotoa tomentosa* (Malpighiaceae). J Nat Hist 31:1307–1312. doi: 10.1080/00222939700770731

Demirel N, Yildirim AE (2008) Attraction of various sticky color traps to *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) and *Empoasca decipies* Paoli (Homoptera: Cicadellidade) in cotton. J Entomol 1:1–6. doi: 10.3923/je.2008.389.394

Dreistadt SH (2001) Integrated pest management for floriculture and nurseries. State integrated pest management. Project university of California division of agriculture and natural resources publication 3402

Fedor P, Dubovský M, Majzlan O (2007) Tree photoeclector in sampling bark-dwelling thrips (Thysanoptera). Thysanopteron, Pismo Entomol 3:14–16

Frey JE, Cortada R V, Helbling H (1994) The potential of flower odours for use in population monitoring of western flower thrips *Frankliniella occidentalis* Perg. (Thysanoptera: Thripidae). Biocontrol Sci Technol 4:177–186. doi: 10.1080/09583159409355325

Funderburk J, Stavisky J, Olson S (2000) Predation of *Frankliniella occidentalis* (Thysanoptera: Thripidae) in field peppers by *Orius insidiosus* (Hemiptera: Anthocoridae). Environ Entomol 29:376–382. doi: 10.1603/0046-225X(2000)029

Grout TG, Morse JG, O'Connell N V, et al (1986) Citrus thrips (Thysanoptera: Thripidae) phenology and sampling in the San Joaquin Valley. J Econ Entomol 79:1516–1523. doi: 10.1093/jee/79.6.1516

Helyer NL, Brobyn PJ (1992) Chemical control of western flower thrips (*Frankliniella occidentalis* Pergande). Ann Appl Biol 121:219–231. doi: 10.1111/j.1744-7348.1992.tb03434.x

Hoddle MS, Mound LA, Paris DL (2008) Thrips of California. CBIT Publishing, Queensland

Irwin ME (1980) Sampling aphids in soybean fields. In: Kogan M, Herzog DC (eds) Sampling methods in soybean entomology. Springer, New York, pp 239–259

Irwin ME, Yeargan K V. (1980) Sampling phytophagous thrips on soybean. In: Kogan M, Herzog DC (eds) Sampling methods in soybean entomology. Springer, New York, pp 283–304

Jones DR (2005) Plant viruses transmitted by thrips. Eur J Plant Pathol 113:119–157. doi: 10.1007/s10658-005-2334-1

Joost PH, Riley DG (2004) Sampling techniques for thrips (Thysanoptera: Thripidae) in preflowering tomato. J Econ Entomol 97:1450–1454. doi: 10.1603/0022-0493-97.4.1450

Kirk WDJ (1984) Ecological studies on *Thrips imaginis* Bagnall (Thysanoptera) in flowers of *Echium plantagineum* L. in Australia. Aust J Ecol 9:9–18. doi: 10.1111/j.1442-9993.1984.tb01613.x

Laudonia S, Pedata PA, Viggiani G (2000) Development of a sequential sampling program for *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) on strawberry in plastic tunnels in Southern Italy. Bull IOBC/WPRS 23:201–204.

Lee HS, Wen HC (1982) Seasonal occurrence of and injury caused by thrips and their control on mangoes. Plant Prot Bull 24:179–187. doi: 10.1111/1750-3841.12171

Lewis T (1959) A comparison of water traps, cylindrical sticky traps and suction traps for sampling thysanopteran populations at different levels. Entomol Exp Appl 2:204–215. doi: 10.1111/j.1570-7458.1959.tb00434.x

Lewis T (1997) Pest thrips in perspective. In: Lewis T (ed) Thrips as crop pests. CAB International, Wallingford Oxford, pp 1–13

Lima EFB (2019) Thysanoptera in Catálogo Taxonômico da Fauna do Brasil. PNUD. Available: <http://fauna.jbrj.gov.br/fauna/faunadobrasil/316>. Accessed: 25 Nov. 2019

Liu TX, Chu CC (2004) Comparison of absolute estimates of *Thrips tabaci* (Thysanoptera: Thripidae) with field visual counting and sticky traps in onion field in south Texas. Southwest Entomol 29:83–89

MacIntyre-Allen JK, Scott-Dupree CD, Tolman JH, Harris CR (2005) Evaluation of sampling methodology for determining the population dynamics of onion thrips (Thysanoptera:

Thripidae) in Ontario onion fields. J Econ Entomol 98:2272–2281. doi: 10.1603/0022-0493-98.6.2272

Mehle N, Trdan S (2012) Traditional and modern methods for the identification of thrips (Thysanoptera) species. J Pest Sci (2004) 85:179–190. doi: 10.1007/s10340-012-0423-4

Monteiro RC (2002) The Thysanoptera fauna of Brazil. In: Marullo R, Mound LA (eds) Thrips and Tospoviruses: Proceedings of the 7th International Symposium on Thysanoptera. Australian National Insect Collection, Canberra, pp 325–340

Monteiro RC, Mound LA (2012) Thysanoptera. In: Rafael JA, Melo GAR, Carvalho CJB, et al. (eds) Insetos do Brasil: Diversidade e Taxonomia. Holos Editora, Ribeirão Preto, pp 407–422

Moreira AN, Oliveira JV, Oliveira JEM, et al (2017) Sampling technique for thrips in vineyards. Rev Bras Frutic 39:1–13. doi: 10.1590/0100-29452017582

Moritz GB, Mound LA, Morris DC, Goldarazena A (2004) Thrips ID: pest thrips of the world. An interactive identification and information system. Canberra, ACIAR. CD-ROM.

Morse JG, Hoddle MS (2006) Invasion biology of thrips. Annu Rev Entomol 51:67–89. doi: 10.1146/annurev.ento.51.110104.151044

Mound LA (2005) Thysanoptera: diversity and interactions. Annu Rev Entomol 50:247–269. doi: 10.1146/annurev.ento.49.061802.123318

Mound LA (2014) Austral Thysanoptera: 100 years of progress. Austral Entomol 53:18–25. doi: 10.1111/aen.12054

Mound LA, Marullo R (1996) The thrips of Central and South America: an introduction (Insecta: Thysanoptera). Associated Publishers, Gainesville, Florida

Mound LA, Terry I (2001) Thrips pollination of the central Australian cycad, *Macrozamia macdonnellii* (Cycadales). Int J Plant Sci 162:147–154. doi: 10.1086/317899

Mound LA (1997) Thrips as crop pests. In: Lewis T (ed) Biological diversity. CAB International, Wallingford, pp 197–215

Muvea AM, Waiganjo MM, Kutima HL, et al (2014) Attraction of pest thrips (Thysanoptera: Thripidae) infesting French beans to coloured sticky traps with Lurem-TR and its utility for monitoring thrips populations. Int J Trop Insect Sci 34:197–206. doi: 10.1017/S174275841400040X

Nault BA, Shelton AM (2010) Impact of insecticide efficacy on developing action thresholds for pest management: a case study of onion thrips (Thysanoptera: Thripidae) on onion. J Econ Entomol 103:1315–1326. doi: 10.1603/EC10096

Navarro-Campos C, Aguilar A, Garcia-Marí F (2012) Aggregation pattern, sampling plan, and intervention threshold for *Pezothrips kellyanus* in citrus groves. Entomol Exp Appl 142:130–139. doi: 10.1111/j.1570-7458.2011.01204.x

Navas VES, Funderburk JE, Mack TP, et al (1994) Aggregation indices and sample size curves for binomial sampling of flower-inhabiting *Frankliniella* species (Thysanoptera: Thripidae) on tomato. J Econ Entomol 87:1622–1626. doi: 10.1093/jee/87.6.1622

Orosz S, Éliás D, Balog E, Tóth F (2017) Investigation of thysanoptera populations in Hungarian greenhouses. Acta Univ Sapientiae, Agric Environ 9:140–158. doi: 10.1515/ausae-2017-0013

Palumbo JC (2003) Comparison of sampling methods for estimating western flower thrips abundance on lettuce. College of Agriculture and Life Sciences, University of Arizona (Tucson, AZ)

Parajulee MN, Shrestha RB, Leser JF (2006) Sampling methods, dispersion patterns, and fixed precision sequential sampling plans for western flower thrips (Thysanoptera: Thripidae) and cotton fleahoppers (Hemiptera: Miridae) in cotton. J Econ Entomol 99:568–577. doi: 10.1603/0022-0493-99.2.568

Parker BL, Grehan JR, Skinner M (1992) Method for extracting pear thrips (Thysanoptera: Thripidae) from forest soil. J Econ Entomol 85:865–869. doi: 10.1093/jee/85.3.865

Pearsall IA (2000) Damage to nectarines by the western flower thrips (Thysanoptera: Thripidae) in the interior of British Columbia, Canada. J Econ Entomol 93:1207–1215. doi: 10.1603/0022-0493-93.4.1207

Pearsall IA, Myers JH (2000) Evaluation of sampling methodology for determining the phenology, relative density, and dispersion of western flower thrips (Thysanoptera: Thripidae) in nectarine orchards. J Econ Entomol 93:494–502. doi: 10.1603/0022-0493-93.2.494

Pelley RH (1942) A method of sampling thrips populations. Bull Entomol Res 33:147–148. doi: 10.1017/S0007485300026420

Pereira PS, Sarmento RA, Galdino TVS, et al (2017) Economic injury levels and sequential sampling plans for *Frankliniella schultzei* in watermelon crops. Pest Manag Sci 73:1438–1445. doi: 10.1002/ps.4475

Pickett CH, Wilson LT, Gonzalez D (1988) Population dynamics and within-plant distribution of the western flower thrips (Thysanoptera: Thripidae), an early-season predator of spider mites infesting cotton. Environ Entomol 17:551–559. doi: 10.1093/ee/17.3.551

Pinent SMJ, Pinent CED, Botton M, Redaelli LR (2007) Thrips species (Thysanoptera) on strawberry, persimmon and grape in the Gaucho Highlands, Rio Grande do Sul State, southern Brazil. J Insect Sci 7:1–44

Pinent SMJ, Mascaro F, Botton M, Redaelli LR (2008) Thrips (Thysanoptera: Thripidae, Phlaeothripidae) damaging peach in Paranapanema, São Paulo State, Brazil. Neotrop Entomol 37:486–488. doi: 10.1590/S1519-566X2008000400019

Pizzol J, Nammour D, Hervouet P, et al (2010) Comparison of two methods of monitoring thrips populations in a greenhouse rose crop. J Pest Sci (2004) 83:191–196. doi: 10.1007/s10340-010-0286-5

Powelll DM, Landis BJ (1965) A comparison of two sampling methods for estimating population trends of thrips and mites on potatoes. J Econ Entomol 58:1141–1144. doi: 10.1093/jee/58.6.1141

Reisig DD, Godfrey LD, Marcum DB (2010) Grass thrips (*Anaphothrips obscurus*) (Thysanoptera: Thripidae) population dynamics and sampling method comparison in timothy. Environ Entomol 39:1617–1625. doi: 10.1603/EN09329

Rhodes AA, Morse JG (1989) *Scirtothrips citri* sampling and damage prediction on California navel oranges. Agric Ecosyst Environ 26:117–129. doi: 10.1016/0167-8809(89)90022-4

Rieske LK, Raffa KF (2003) Evaluation of visual and olfactory cues for sampling three thrips species (Thysanoptera: Thripidae) in deciduous forests of the northern United States. J Econ Entomol 96:777–782. doi: 10.1603/0022-0493-96.3.777

Riley DG, Joseph S V, Srinivasan R, Diffie S (2011) Thrips vectors of tospoviruses. J Integr Pest Manag 2:1–10. doi: 10.1603/IPM10020

Tamo M, Baumgärtnera J, Delucchia V, Herrena HR (1993) Assessment of key factors responsible for the pest status of the bean flower thrips *Megalurothrips sjostedti* (Thysanoptera: Thripidae) in West Africa. Bull Entomol Res 83:251–258. doi: 10.1017/S000748530003474X

Tanigoshi LK, Moreno DS (1981) Traps for monitoring populations of the citrus thrips, *Scirtothrips citri* (Thysanoptera: Thripidae). Can Entomol 113:9–12. doi: 10.4039/Ent1139-1.

Tappan WB (1986) Relationship of sampling time to tobacco thrips (Thysanoptera: Thripidae) numbers in peanut foliage buds and flowers. J Econ Entomol 79:1359–1363. doi: 10.1093/jee/79.5.1359

Ugine TA, Sanderson JP, Wraight SP, et al (2011) Binomial sampling of western flower thrips infesting flowering greenhouse crops using incidence-mean models. Environ Entomol 40:381–390. doi: 10.1603/EN10085

Walsh B, Maltby JE, Nolan B, Kay I (2012) Seasonal abundance of thrips (Thysanoptera) in capscium and chilli crops in South-East Queensland, Australia. Plant Prot Q 27:19–22.

Welter SC, Rosenheim JA, Johnson MW, et al (1990) Effects of *Thrips palmi* and western flower thrips (Thysanoptera: Thripidae) on the yield, growth, and carbon allocation pattern in cucumbers. J Econ Entomol 83:2092–2101. doi: 10.1093/jee/83.5.2092

Werner SM, Nordheim E V, Raffa KF (2004) Comparison of methods for sampling Thysanoptera on basswood (*Tilia americana* L.) trees in mixed northern hardwood deciduous forests. For Ecol Manage 201:327–334. doi: 10.1016/j.foreco.2004.07.014

Tables

Table 13.1 A brief description of the parameters used to sample thrips.

Parameters of sampling	Description
Relative or absolute	The relative infers only a proportion of thrips infesting plants and crops; while the absolute permits the estimation of all thrips
Destructive or non-destructive	The destructive sampling requires the removal of plant parts, while the non-destructive permits the evaluation of thrips density without the need to extract plant structures (e.g. leaves, flowers, stems)
Disturbing or non-disturbing	Whenever a sampling method requires touching and shaking the plant, and/or removal of plant parts, it is disturbing, because some thrips may fly away or drop from plant during this process
Selective or non-selective	Whether the sampling permits to capture a target thrips species or if it captures several species at once
Direct or delayed	Some techniques permit the counting of thrips in the field (in-situ), whereas in others it is necessary to take the sample to the laboratory to count these insects
Limited or unlimited	Depending on the method, the samples can be saturated and no thrips can be further collected. Some other techniques permit unlimited sampling of thrips
Complete or incomplete	Whenever the sampling accounts for adults and immatures of thrips, it is complete. However most sampling targets adults only
Repetition or non-repetition	Sometimes a sampling method can be repeated in the same plant structure or crop to monitor thrips in time and space, but in other occasions, this cannot be done, for instance when parts of the plant, or even the whole, are extracted

Table 13.2 Main characteristics of the methods used to sample thrips. A brief description of each parameter can be found in **Table 13.1**.

	Parameters of sampling						
Sampling techniques	**Destructive**	**Disturbing**	**Specific**	**Direct**	**Limited**	**Complete**	**Repetition**
Binomial sampling	no	no	yes	yes	no	yes	yes
Direct counts	no	no	yes	yes	no	yes	yes
Beating	no	yes	no	yes	no	yes	yes
Sticky traps	no	no	no	yes	yes	no	yes
Plant part extraction	yes	yes	no	no	no	yes	no
Washing off the plant part	no	yes	no	no	no	yes	yes
Odor baits	no	no	no	yes	yes	no	yes
LEDs in sticky traps	no	no	no	yes	yes	no	yes
Caged sticky cards	no	no	no	yes	yes	no	yes
Immobilization with CO_2	no	yes	no	yes	no	yes	yes
Light traps	no	yes	no	no	no	yes	yes
Tanglefooted-tile	no	no	no	yes	yes	no	yes
Aspirator or suction traps	no	yes	no	no	no	yes	yes
Electric vacuum device	no	yes	no	no	no	yes	yes
Sweep nets	no	yes	no	no	no	yes	yes
Pupation papers	no	no	no	yes	yes	yes	yes
Shotgun	yes	yes	no	no	no	yes	no
Flotation	no	no	no	no	no	yes	no

Figure legends

Fig. 13.1 Thrips infesting *Enterolobium* sp. (Fabaceae) in a greenhouse in Brazil. In a short period of time (less than a month) thrips devastated the plants, leaving several scars on the leaf surface. Herbivory by thrips eventually resulted in defoliation. The last photo shows the larvae of thrips (circles). Because of their small size, thrips can be seen in plants only when it is too late, as in this *Enterolobium* individual. Photos by EAS.

Fig. 13.2 Bipartite representation of thrips and their host plants. *Frankliniella occidentalis*, *F. schultzei* and *Thrips tabaci* were found in many crops and can be considered highly polyphagous. The likelihood of their attacking several crops is thus high. The data comprises part of a large dataset that was extracted from 64 studies that focused on thrips sampling and monitoring. The figure was made using *R* statistical software (bipartite package), and we show only thrips species that were sampled in three or more different crops.

Fig. 13.3 Pervasiveness of *Frankliniella* and *Thrips* as the genera with more species in samplings of thrips.

Fig. 13.4 Frequency distribution of the thrips species in samplings of thrips in crops.

Fig. 13.5 (a) Yellow and (b) blue sticky traps used to monitor thrips inside a greenhouse (c). In some cases, odor baits can be added to the sticky traps, either to maximize thrips capture or to trap specific pest species. Photos by RM.

Fig. 13.6 Direct counts of the thrips *Heterothrips peixotoa*. (a) Thrips within the stamens of *Banisteriopsis stellaris* are seen under a stereomicroscope with 10x magnification. (b) Several thrips foraging on the petals, the chamber and the stamens of *B. stellaris*, thus making it difficult to estimate their density. (c) Thrips hiding in between the leaves of *B. malifolia*. A non-experienced researcher might miss these insects or may even not distinguish them from other insects. (d) A single individual thrips foraging on a flower bud – in these cases the number of thrips can be recorded with precision. (e) High density of thrips in a petal of *Cochlospermum*

regium. Thrips' small size and sensitivity to disturbance calls for caution when estimating their numbers in this situation. Photos by EAS.

Figure 1

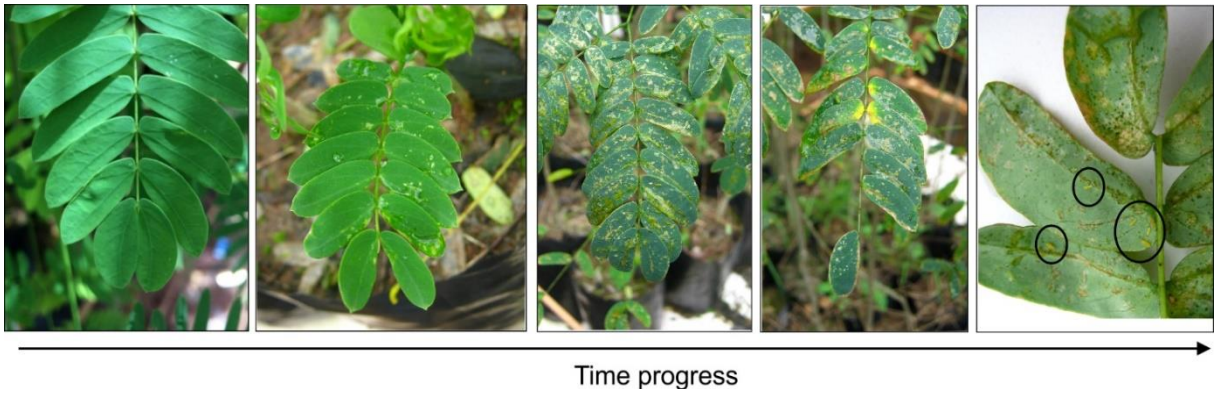

Figure 2

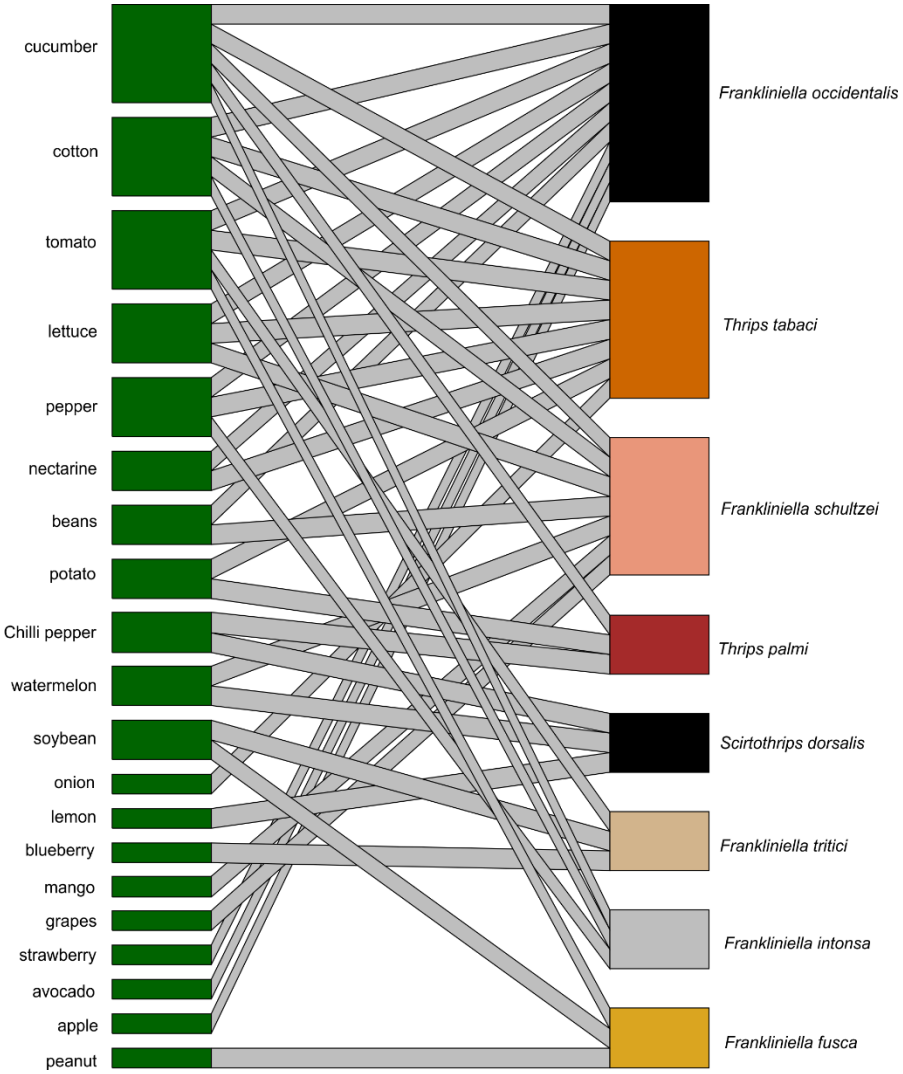
cucumber
cotton
tomato
lettuce
pepper
nectarine
beans
potato
Chilli pepper
watermelon
soybean
onion
lemon
blueberry
mango
grapes
strawberry
avocado
apple
peanut
Frankliniella occidentalis
Thrips tabaci
Frankliniella schultzei
Thrips palmi
Scirtothrips dorsalis
Frankliniella tritici
Frankliniella intonsa
Frankliniella fusca

Figure 3

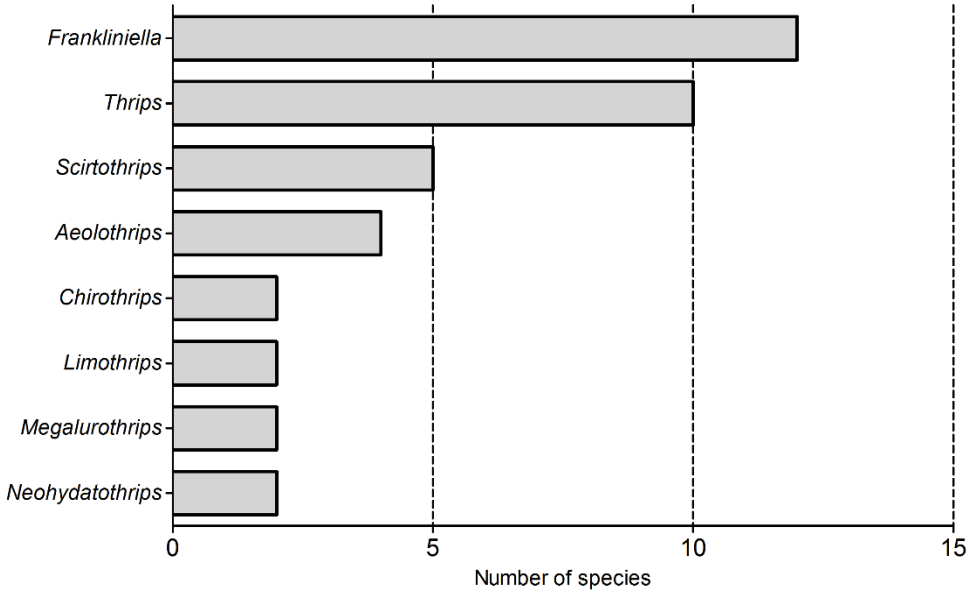
Frankliniella
Thrips
Scirtothrips
Aeolothrips
Chirothrips
Limothrips
Megalurothrips
Neohydatothrips
0
5
10
15
Number of species

Figure 4

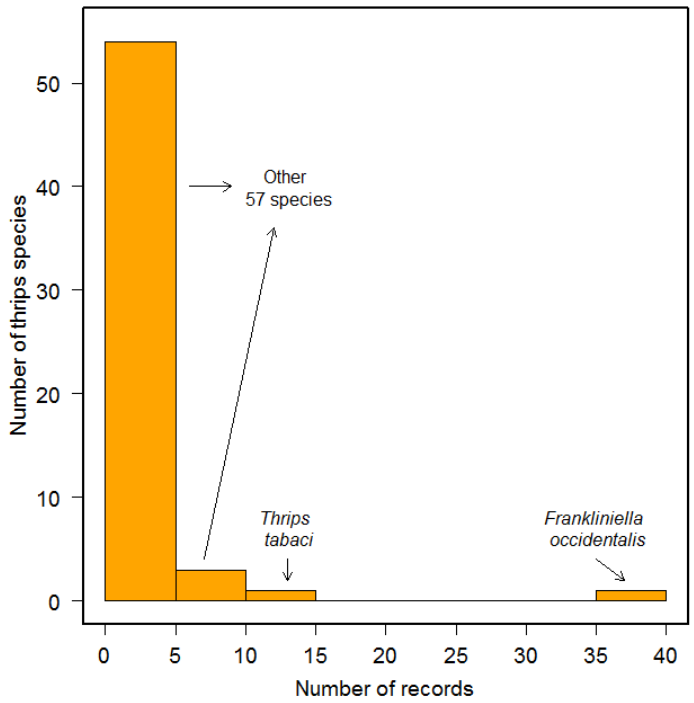
Number of thrips species
0
10
20
30
40
50
Other
57 species
Thrips
tabaci
Frankliniella
occidentalis
0
5
10
15
20
25
30
35
40
Number of records

Figure 5

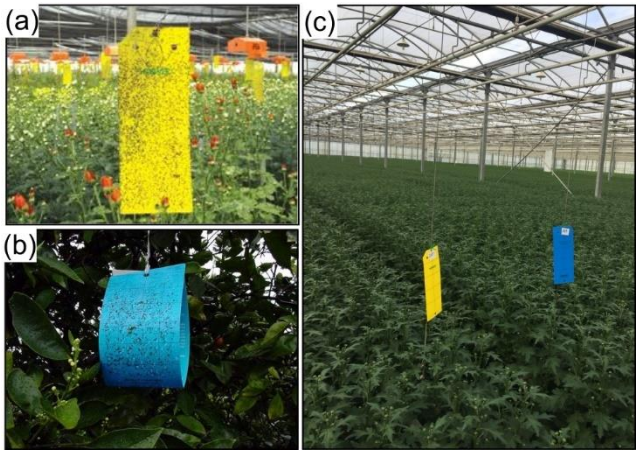

Figure 6