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Thrips: a review of sampling methods in relation to their habitats

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Abstract

This review focuses on the sampling methods for thrips (Thysanoptera) in relation to their interactions with different colonized habitats. The study is based on a bibliographic search from Google Scholar and CAB (Agricultural Series) websites which provided the thematic articles mainly published between 1980 to 2020. Among them, only those referring to reliable data for clearness and meticulous descriptions have been considered. Furthermore, the most useful collecting methods and techniques concerning the main settled habitats by thrips, have been inspected. The results could suggest pattern which considers very varied sampling methods, in order to evaluate thrips biodiversity, together with pointing out the advantages and disadvantages that each of them can provide through their use.

Key words: monitoring, traps, habitats, hosts, Thysanoptera.

Introduction

The commonly known thrips belonging to the order of Thysanoptera, represent a group of the minuscule insects (the adult body length can vary from 0.5 to 15 mm), which have not been analysed in depth and have often been disregarded in long-term works on animal biodiversity. Thrips are even mostly overlooked in ecological studies, regardless of their role in multitrophic interactions. Usually considered to have an opportunistic lifestyle, thrips exhibit varied lifestyles, occupying several niches, habitats and ecosystems.

Although they exhibit such diverse habits, Thysanoptera are best known for the economic damages they cause in several crops. Their agricultural importance involves direct damage to plant tissues during oviposition and feeding activities. The most common damages associated with thrips are the shading and chlorosis of leaves and flowers and the malformations of fruits. Infestations can destroy terminal buds, triggering unnecessary branching of the plants and deferred plant growth. These symptoms arise as a consequence of the thrips suctioning the internal contents of individual plant cells (Kirk, 1997). At the time of feeding, several phytopathogenic agents that trigger disease in plants may be passed, so that, thrips can be vectors of viruses, fungi and bacteria (Jones, 2005).

Viruses of the genus *Tospovirus* occur all over the world, can cause significant economic losses in several important crops (Whitfield *et al.*, 2005) and are the most important thrips-vectored organisms. Fungi and bacteria are presumably transmitted by mechanical contact and movement of the pathogen on thrips body surfaces. Although several diseases of economic importance are transmitted in this way by thrips, their role as vectors of fungi and bacteria has not been widely investigated (Ullman *et al.*, 1997).

Only about 2% of the described thrips species are recorded as pests, there are several major pest species of worldwide distribution: *Thrips tabaci* Lindeman is a major pest of onion and garlic, *Thrips palmi* Karny attacks various vegetables and fruit trees, *Frankliniella occidentalis* (Pergande) have great importance in horticultural and ornamental plants and *Frankliniella schultzei* (Trybom)is highly polyphagous (Lewis, 1997). Viruses transmitted by thrips infect more than 1000 plant species (Riley et al., 2011).

The objective of this study is to review the main sampling methods for thrips and to provide a help for detailed field studies and meticulous monitoring. We also explore the main habitats of thrips and select the most useful methods for sampling, describing them in the basic structure, focusing the usefulness and the possible lacks.

Field inventories and taxonomy

Field samplings and surveys tend to reveal most thrips biodiversity occupying distinct niches, and in case of pest species, represent the most important step to prevent and monitoring potential damaging species. Therefore that, the diagnosis of species represents the basic useful knowledge of any sampling program. The identification of thrips species is generally based on the morphology of adult females and males (when available), involving permanent slide mounting in Canada balsam for visualisation under a light microscope (Mound and Marullo, 1996). Classical morphological identifications require long years of experience of basic character states, discriminating different groups of taxa and specialist collections as comparisons. Instead, identification of immatures specimens is available only for a small number of species (Speyer and Parr, 1941; Priesner, 1964; Heming, 1991; Vierbergen *et al.*, 2010). Studies that are more recent have provided molecular methods for identifying especially pest species (Mehle and Trdan, 2012), including the real-time polymerase chain reaction restriction fragment polymorphism and the restriction fragment length polymorphism. The use of gene fragments as internal transcribed spacers, and mitochondrial cytochrome oxidase (mt COI), of which the COI-DNA barcoding technique has proved to be a highly reliable and efficient method to identify also problematic species (Marullo *et al.*, 2020). This technique has provided the discovery of species complexes among Thysanoptera, including species of economic importance (Rugman-Jones *et al.*, 2010; Dickey *et al.*, 2015; Gikonyo *et al.*, 2017). Besides a number of works dealing with DNA barcoding, molecular keys are now available for several groups (Moritz *et al.*, 2004; Rugman-Jones *et al.*, 2006; Timm *et al.*, 2008; De Grazia *et al.*, 2016). This type of identification is especially relevant for economic or quarantine interests because of the faster results, although the costs involved are high. Moreover, the DNA barcoding technique provides the identification at species level also from eggs or larval stages.

Samplings of thrips, just like other animals, allow the evaluation of several factors that might increase our knowledge of different aspects of their life history, such as:

- the distribution in the ecological functional groups: pollinators, herbivores, fungus-feeders and predators;
- the measurement of endemism and assessment of rare and endangered species: these studies aid in conservation strategies referring to species exerting an important role in the ecosystem;
- the wire-tapping/monitoring of immigrant or exotic species: these studies allow rapid evaluation of invasive species that might become pests, suggesting actions that can be anticipated in order to prevent a burst of populations (Morse and Hoddle, 2006);
- the evaluation of patterns of host exploitation, i.e. the monitoring of thrips population on leaves or fruits in a crop to establish a niche overlapping or competition.

Bibliographic search and survey

The literature research was conducted screening Google Scholar and CAB abstracts (CABI, 2020), which indexes databases and full-text papers from the main journals and publishers websites. The available literature has been surveyed to investigate the sampling methods utilized collecting thrips, both on crops or living habitats, and the thrips species.

The articles referring to monitoring/sampling methods for thrips species were considered for the reordering in this review, and among them, mainly those published from 1980 to 2020.

Finally, about ninety papers were chosen according to the authors' names, the reliability of the main data recorded (the name of the thrips species, the method or technique of sampling/collecting and the plant or crop, the habitat or the studied area) and the meticulousness of their description.

Classification of sampling methods for thrips

Sampling methods for thrips can be distinguished in absolute if they provide for the counting of all thrips specimens, adults and pre-imaginal stages, living on a whole plant (table 1) (Liu and Chu, 2004; Joost and Riley, 2004) and regard low-sized crops or seedlings (Palumbo, 2003). This method foresees that plants are put in bags and taken in the laboratory and then filled with ethanol and shaken in order to collect all the thrips specimens. The ethanol is filtered and thrips are counted. It is also possible to avoid the removing of a whole plant, and to collect a given plant structure to estimate the thrips density in laboratory (Aliakbarpour and Rawi, 2010). Diverse methods are considered relative because they allow collecting only a few species of thrips living on a plant and their direct counting in field or in laboratory after cutting parts of a plant (Irwin and Yearson, 1980). In this case, relative methods are called destructive and delayed methods. Instead methods providing thrips counting in field, without removing any part of a plant, are considered direct and non-destructive (Pearsall and Myers, 2000; Muvea *et al.*, 2014). Moreover, they can also classified as disturbing methods in case the technique requires touching and shaking the plant or removing plant parts, because some thrips can fly away or fall down. Despite most methods target only adults thrips, and in this case can be classified as incomplete methods, some others provide for accounting both adults and immature stages (complete methods). Selective methods, such as sticky traps or use of odours, colour, etc., are so called because the response to such tools is species-specific. Instead, non-selective methods, i.e. beating, provide for the capture of all thrips species feeding on a plant structure.

Collecting or sampling methods for thrips belonging to different environments

Soil, litter, fungi, hanging dead leaves, tree bark

Leaf litter under trees is the habitat of fungus feeders Thysanoptera which constitute half of the known thrips species, all belonging to the family Phlaeothripidae (Tree and Walter, 2012; Mound *et al.*, 2013). Some of these thrips feed on fungal spores (Mound, 1972; 1974). Spore feeders live in leaf litter at the base of grass tussocks and feed on dead hanging leaves, instead fungal hyphae feeders can live either at ground level in leaf litter or above ground on dead twigs and branches as well as some species, in the sub-family Idolothripinae, in hanging dead leaves on dead branches in the canopy. Furthermore, soil and leaf litter are also suitable habitats for many other thrips species to pupate and reach the adult stage: they are flower's thrips associated with trees, crops and wild and horticultural plants, on which they live and breed as adults and young larvae ,feeding on flowers and leaves, but the mature larvae fall to the ground or in the litter where the metamorphosis is completed. Such species belong to families Aeolothripidae (flowers's thrips and obligate/facultative predatory thrips), Thripidae and Phlaeothripidae (phytophagous thrips).Their mature larvae and pupae can be collected by using some methods described below.

Table 1. Classification of the main sampling thrips methods.

Methods	Destructive	Non-destructive	Disturbing	Non-disturbing	Direct	Delayed	Complete	Incomplete	Selective	Non-selective
Relative methods										
Soil set corers		X		X		X		X		X
Berlese- Tullgren funnels	X		X			X	X			X
Flotation	X		X			X	X			X
Emergence trap		X		X		X		X		X
Screen trap		X		X		X		X		X
Beating	X		X			X	X		X	
Sweep net		X	X			X	X			X
Direct counting		X		X	X		X		X	
Turpentine funnel	X		X			X	X		X	
Suction trap		X	X			X	X		X	
Sticky traps		X		X	X			X		X
Water trap		X		X		X		X		X
Photoeclectors/light traps		X	X			X	X			X
Binomial sampling		X		X	X		X		X	
Absolute method										
Plant washing		X		X	X		X		X	

S o i l   s e t - c o r e r s

In order to remove soil-living thrips (also pupae under several crops), soil set-corers can be used. A soil set can be constituted by six soil metallic corers - 2.5 cm diameter × 15 cm deep - which provides a soil sample. Samples can be collected up to 25 cm under ground level, although in countries with temperate climates thrips can found at a depth of up to 80 cm. The sample size might range from 500 to 20,000 cm^3 of soil, for ordinary density of thrips occurring in field and considering a mean of 1 thrips/sample provided by a standard set-corers (Lewis, 1973).

The method allows the sampling of population of thrips species living in particular areas or crops but requires high work's expenses.

B e r l e s e - T u l l g r e n   f u n n e l

Leaf litter is more commonly sampled by area or volume, as weight may differ depending on the dry state of the samples. Thrips within the samples can be collected through a Berlese-Tullgren funnel which uses heat and light to extract insects. Berlese-Tullgren funnels are usually made of metal, but when using wet litter and/or soil collapsible cloth funnels can be used to avoid condensation. The sample bed comprises a metal mesh, on which freshly collected soil/litter is spread out, and incandescent light bulbs with a low temperature gradient (10 W bulb) to prevent the soil from drying out, are placed above the sample. After 2-3 days, the insects (and other organisms) in the sample are driven downwards as it dries out, and they are collected in containers filled with AGA solution (10 parts of 60% ethyl alcohol + 1 part of glycerine + 1 part of acetic acid) or in 95% or 70% ethanol (Kobro and Rafoss, 2001; Tree and Walter, 2012; Belaam-Kort *et al*., 2020).

F l o t a t i o n

Since funnel methods permit to collect mainly the adult thrips, flotation method is recommended to collect larvae and pupae. In this case, after soil samples have been filtered through sieves with decreasing mesh, heptane is used to separate the young thrips specimens from residue and to float (Parker *et al*., 1992).

E m e r g e n c e   t r a p s

Another possibility for terrestrial populations is to place an emergence trap on the ground surface, to catch adult specimens that emerge from the soil. Generally, these traps have a conical or pyramidal structure with dark walls and a glass vial at the top or in the sides where thrips will be collected as soon as they fly to the light. The traps require to be cleaned from soil residues and other arthropods emerged. The use of this approach has provided satisfactory duration of emergence for *Taeniothrips inconsequens* (Uzel) (Laudermilch, 1989; Maier, 1992) and for for *Thrips calcaratus* Uzel (Raffa *et al*.,1992). A similar trap comprising a PVC cylinder placed on the soil and covered with a clear lid coated with sticky grease has proved effective and cheaper than cone traps to monitor *T. inconsequens*. The best size for cylinder is 7.6 cm in diameter (Parker and Skinner ,1993), and cylinders 20 cm in diameter and 10 cm tall were used for monitoring *Scirtothrips citri* (Moulton) in California and Arizona. Clear acetate discs with sticky grease on both sides were placed on the upper end of cylinders, for catching larvae falling from trees to pupate in the soil and, in different positions, adults emerging from the surface soil and litter. The acetate discs were collected in separate , clear vinyl folders for ease of handling, storage and counting (Tanigoshi and Moreno, 1981).

Photoeclectors/light traps

A tree equipment is based on a principle of positive phototaxy, negative geotropism and outline orientation shown by arthropods (Fedor *et al.*, 2007; Dubovsky *et al.*, 2010). It is constituted by black cotton funnel, fixed to a PVC tube of 5 cm of diameter. The tube is scratched to allow an easier movement of the arthropods. A PET bottle, used as collecting jar, is sleeved on the tube and covered by another bottle. The cotton funnel is fixed into the bark with a wire and cement filling the empty space between the trunk and the equipment. A conservative liquid suggested is constituted by 96% ethanol (25%), surfactant (5%) and water (70%). Traps are usually exposed on several height levels, i.e. 1, 2, 3 or more metres from the ground, because the stratification of corticicolous populations and varied distribution of the species on trunks. A modified version of the tree photoeclector is the soil photoeclector that is constructed of plastic walls with a metal bar frame covered by textile and equipped with jar on the top. It is used to cover isolated space over soil area of 1 m^2. A solution of ethylene glycol is used as conservation liquid. Both the traps have been recorded as suitable to collect obligate thrips predators of mites, such as *Scolothrips longicornis* Priesner, and facultative predators and flower's thrips species belonging to family Aeolothripidae, i.e. *Aeolothrips vittatus* Haliday (Masarovic *et al.*, 2013a; 2013b).

Screen trap

In reserves and national parks where human interventions are minimal, a large diversity of tree ages, including those in various stages of decay, is maintained and the local populations of fungivorous and bark-dwelling thrips are numerous, a useful collecting tool is the screen trap. The standard type is the IBL-2 screen trap which consists of a triangular screen with a translucent polythene funnel affixed to a one-litre bottle filled with an aqueous solution of ethylene glycol as a preservative. The upper side of the inverted triangle is covered with a small roof and no attractive substance is used. These traps are hung about one metre above the ground between the trunks of the predominant tree species in the sampling plot (Kucharczyk *et al.*, 2015).

Fresh vegetation (leaves, shoots, flowers, fruits, grasses), air

The available data show that about half of the known thrips species (mostly belonging to Thripidae and Phlaeothripidae families) are related to vegetable habitats and that the plants are sought as reproductive or feeding hosts (Mound and Marullo, 1996). The biology of phytophagous thrips seems to be adapted to flowers and young leaves, but more recent adaptations have also included dead leaves and branches. The very small size, dispersive ability and speed at moving from one habitat to another allow them to adapt to agricultural and horticultural sites as pests. Moreover, thrips natural populations can be moved by a windy mass air and reach different environments on vegetation. The use of different traps varies in consideration of the height of vegetation exposed to the flows of aerial thrips. So that it is possible to distinguish between sampling from exposed plant sites, about two metres above the ground or across the tip of vegetation (Lewis, 1973).

Plastic beating trays

An easy and simple method to collect thrips is to beat flowers together with vegetation, branches and leaves over a small plastic tray or counting board (Powell and Landis, 1965). Using a narrow-bladed heavy trowel as a beating instrument allows the collection of thrips from individual leaves and flowers and the certainty of their host association (Mound and Marullo, 1996). Thrips can be collected with a fine brush and placed in vials containing 70% ethanol for further identification. The beating method is useful for temporal monitoring of abundant populations of thrips on plants and provides the identification of all species that infest plants, including both adults and larvae. This method has revealed, in some studies, different temporal variations of thrips species and their rise and collapse during years (Aliakbarpour and Rawi, 2010; Orosz *et al.*, 2017).

Sweep net

It is a funnel-shaped net, 38 cm diameter, attached to a long handled frame that is swept back and forth, in a 180° arch, through grass, tree and shrub foliage (Reising *et al.*, 2010). It is considered the most suitable tool for the collecting of located populations, in not too wet climate conditions, because the timing of collecting , e.g. after the evaporation of dew, is an important factor.

Turpentine-funnel method

Another method to collect both adults and larvae is to put the flowers into a Berlese-Tullgren funnel, using as a stimulant a drop of turpentine on a plaster block to drive thrips into a collecting tube. The turpentine-funnel method is the most efficient method for collecting thrips on horticultural crops, i.e. about 100% of adults and second instar larvae of *F. occidentalis* from strawberry flowers (Gonzalez-Zamora and Garcia-Marì, 2003). The turpentine procedure ensures that the flower funnels standardise the volume of sampled flowers that fits into a screw-top plastic jar. A few drops of turpentine on a cotton wick are placed on top of the flower sample, which causes the thrips to move to the bottom of the container where they can be collected and preserved in 80% ethanol (Evans, 1933). Adults and larvae specimens are extracted within 30 minutes of exposure to turpentine vapour (Schellhorn *et al.*, 2010). On the same crops, the visual method, which comprises flower examination in the field and count all the thrips that can be seen with the help of a magnifying lens, and can be recommended for a routine field sampling of adults from plots regularly sprayed with insecticides (Gonzales-Zamora and Garcia-Marì, 2003).

Plant washes

Plant washes can be used in crops where plants or plant organs are sampled randomly. The vegetable samples are placed in sealed plastic containers or jars of a proportional size to the sample, containing a solution of water, detergent and 70% ethanol that is agitated for about 20 seconds and repeated at intervals (every 10 minutes) for

2 hours. The water content is poured and filtered through a fine mesh filter. The plants need to be washed with water and 70% ethanol to ensure that all specimens are collected and can be visualised under a stereomicroscope (Burris *et al.*, 1990; Palumbo, 2003; Albedaño *et al.*, 2008).

Direct sampling counts

Direct sampling counts (plant beating, visual counting and plant washes) are advantageous because the researcher can be assured that the species is indeed in the studied substrate. Moreover, direct sampling provides information on immature individuals and brachypterous or apterous specimens that are rarely caught on sticky traps (Reising *et al.*, 2010). Recently, a sampling plan based on direct count of damages on young fruits and leaves has been carried out to evaluate the real impact of pest activity by *Liothrips oleae* (Costa) in specialized olive crops of South Italy, showing the straight relationship between the field olive thrips populations and the increase of damages (Vono *et al*., 2020).

Suction traps

Suction traps (aspirator) are devices that use a flow of air directed over a net to catch thrips and other arthropods. The standardized volume of air is produced by an air-filtering cone enclosed in a cylinder and fed by a timed engine. These traps are useful to monitor thrips' early abundance on vegetable crops, such as tomatoes, that cover a relatively large area (Lewis, 1959; Joost and Riley, 2004). A useful suction trap used to collect thrips species in Central Europe (Hungary) was constituted by a tunnel (12 cm diameter) and situated in 1 ha of fruit-trees field, at height of 6 m. A fan drove about 1000 m^3 air hourly through the tube. The thrips sucked were oriented into a glass container attached to the base of a cone shaped plastic net of fine mesh. The net and the glass container were fastened to the lower end of the suction tube inside the box. The insect were preserved in a mixture of 70% ethanol and glycerine. Such tools provide the captures of thrips species only from mass-flights (Jenser, 1981). Suction traps have been used to collect *Thrips australis* (Bagnall) during their nocturnal flights in warm-weather Australian areas (Laughlin, 1977). Larger suction traps are operated continuously in fixed positions to sample the air also at a height of 40 m. The traps are useful to monitor the migrating populations of a species. Small versions can also be set in a field or carried on a knapsack frame so that different parts of a crop can be sampled. The smallest ones are useful also to collect the natural enemies of thrips.

Sticky traps and cards

Sticky traps and cards are used in open fields and, preferably, in greenhouses for monitoring the early presence of a pest species, the population build-up and the seasonal changes in pest activity. These traps have the inconvenience of damaging thrips when they attach to the trap material, thus making their identification difficult. However, for a crop area with more or less delimited abundance of thrips, they can be an easy means to assess and monitor the thrips' presence and the seasonal changes. Sticky traps are mainly flat (horizontal or vertical) or cylindrical. For sampling in open fields, cylindrical surfaces are more efficient because the surrounding airflow is less turbulent and catches insects from all directions (Lewis, 1997). In greenhouses, where wind is more or less constant, flat cards just above the crop are a good means to monitor thrips populations (Shipp, 1995). As three-dimensional shapes have high costs, flat or cylindrical traps are recommended (Vernon and Gillespie, 1995; Manali and Lim, 2010). Their colour (yellow, white, blue) and chemical attractants are chosen according to the preference shown by the different thrips species (Tommasini and Maini, 1995). For example, blue shades are more effective than white and yellow ones for *F. occidentalis* surveys (Brødsgaard, 1989). For monitoring purposes, these traps are best placed within a metre of the crop level. Traps can also be exposed at different heights to estimate relative density profiles, providing the catches are corrected for relative wind speeds above the crops (Lewis, 1959). Yellow sticky traps have been recorded as appropriate tools to sample *T. tabaci* infesting garlic, onion and tomato crops in field (Gharekhani *et al*., 2014), and also to catch the facultative thrips predator *Aeolothrips intermedius* Bagnall. Sticky traps employed for mass trapping possibly limit *F. occidentalis* hotspots, but also, Trdan *et al*. (2005) demonstrated that coloured sticky traps are not efficient for controlling this species on protected cucumber crop. Moreover, simulation models on population control of *T. palmi* in cucumber greenhouses have suggested that they are effective only at very low pest densities (Lewis, 1997).

However, more recent studies have demonstrated that the addition of substances to sticky traps is recommended in some cases. In strawberry crops, the use of blue sticky cards with *F. occidentalis* aggregation pheromone -neryl (S)-2-methylbutanoate- doubled the number of thrips captured when compared with traps without the pheromone (Sampson and Kirk, 2013). In this case, the authors also concluded that the cards could be used as mass traps for thrips management in strawberry and other high-value crops. On fruit trees, such as peach or nectarine trees, sticky traps are useful only for general *F. occidentalis* population trends and are less efficient than the method of collecting nectarine buds and counting thrips method (Pearsall and Myers, 2000).

Water traps (also pan traps)

Literature results have reported the usefulness of the catching of some species by water traps, which are partially filled yellow coloured plastic bowls or lipped trays with collecting fluid. Water traps for collecting thrips should be about 6 cm deep with a surface area from 250 to 500 cm^2, preferably round and with the water level about 2 cm below the rim. In this trap, a drop of formaldehyde is added to prevent algal and fungal growth, and a few drops of detergent are useful to prevent thrips to escape. In addition, attractive substances and colour can be added to favour the catching of a species. The movements of *Thrips imaginis* Bagnall in Australia have been studied with the use of floral colour and scent (Kirk, 1987).

Table 2. Sampling thrips methods on crops.

Crop	Pest thrips species	Sampling Methods	References
Onion	*Thrips tabaci* Lindeman	Sequential and Binomial plan (direct counting of thrips specimens on plant, washing plants)	Suman and Wahi, 1981; Shelton *et al*., 1987
Potato	*Thrips palmi* Karny	Binomial plan (direct counting on leaves)	Cho *et al*., 2000
Strawberry	*Frankliniella occidentalis* (Pergande)	Sequential sampling plan (shaking flowers)	Laudonia *et al*., 2000
Cucumber	*Frankliniella occidentalis* (Pergande)	Sequential sampling plan (sticky cards, direct counts on flowers and leaves)	Wang and Shipp, 2001
Timothy grass (*Phleum pratense*)	*Anaphothrips obscurus* (Muller)	Direct observations, beat cup, tiller washing, sweep net and sticky cards	Reising *et al*., 2010
Cotton	*Frankliniella schultzei* Trybom	Direct counting thrips (adults and larvae) on whole plants	Fernandes *et al*., 2011
Watermelon	*Frankliniella schultzei* Trybom	Counting of thrips specimens on apical leaves and plant branches	Pereira *et al*., 2016
Roses	*Scirtothrips dorsalis* Hood	Counting of thrips specimens on buds and flowers	Aristizabal *et al*., 2016
Citrus	*Pezothrips kellyanus* (Bagnall)	Collecting of fresh flowers and fruitlets and counting of thrips, sticky cards on external canopies of trees to collect larvae and adults, collecting of all thrips specimens from soil and litter using Berlese funnels	Navarro-Campos *et al*., 2012; Belaam-Kort *et al*., 2020

Binomial sampling

This method regards data collected on a pre-determined number of units and are classified according to two levels of a categorical variable. So that it is based on the presence or absence of thrips and there are difficulties to count all the thrips specimens in a plant or plant structures (Ugine *et al*., 2011). The action is undertaken when the level of thrips in plants is reached a given threshold, for example 50% (table 2).

Sampling methods involving absolute (i.e. visual counting of thrips on vegetation in field) (Bonsignore and Vacante, 2012) or relative (i.e. extraction and counting of thrips in laboratory) surveys of pest thrips have been described for several crops related to applied entomology projects, although the action levels for implementing control tactics may differ among distinct areas of the world. Some examples in table 2 are referred to the main worldwide-distributed thrips species and harmful on largely grown vegetables and crops.

Airborne thrips populations

The sampling of aerial thrips populations could be considered easier than terrestrials but the results obtained could be often unsatisfactory if a detailed sampling project and a clear aim to pursue have not been provided in order to choose a type of trap. As previously recorded, different traps can be used on the height of vegetation exposed to the flows of airborne thrips populations. So, that the monitoring can be done over the tip of vegetation (i.e. more than two metres above soil) or below in case of smaller plants. In the first case suction traps and screen traps can be considered suitable, instead sticky traps and water traps are preferred to sample on smaller plants.

These trap methods can't determine the abundance and proportion of each species present in the mixed populations flying above a crop. The reliable values of population density, or the daily periodic flights can be realized by using suction traps. A suction trap exposed below two metres is able to catch samples with thrips specimens clean and easily identifying. However, in case of sampling air dense population, when the crops exibit heavy infestations, the catches are too large and provide samples not useful to be evaluated. Wind is the only environmental variable effecting the efficiency of suction traps but the effect is small in wind speeds less 15 km/h (Lewis, 1997). The main disadvantages of suction traps are the costs and the high consuming power. So that they have no large application for routine thrips monitoring. Only in case of large scale system for major pests they can be used and provide the advantage to study on composition, behaviour and dispersal of pest populations (Jenser, 1981).

Quarantine plant materials

These "environments" are constituted mainly by ornamental plants, vegetables, fruits, wood and parts of trees that are commodities transferring between countries in the world trade. Most thrips species have a broad host plant range and can be associated as pests with varied plants. Despite thrips have limited natural spread, they can be transported over very long distances with plant material. Some of them can be often recorded as quarantine/alien pest species, recorded in Pest Risk Lists, when their introduction from the origin country to the new introduced ones, is forbidden by the international trade agreements, because their high potential pest activity in the entry territories. Therefore, for example, *T. palmi* is considered the main quarantine species for the EU Countries (Augustin *et al*., 2012). The surveillance techniques for the detection of invasive exotic thrips suggest the checking of the typical symptoms due to thrips attacks on vegetables inspected and the monitoring of thrips adults or larval stages using blue or yellow sticky traps or water traps. The colour is attractive for thrips adults over short distances, and the adding of odours or pheromones improve the trapping efficacy (Kirk, 1985; Teulon *et al*., 1993; 2007; Murai *et al*., 2000; Davidson *et al*., 2008). Once thrips have been intercepted, their identification to species level is based on either morphological characteristics or molecular primers. For the EU Region diagnostic protocols are available for this purpose (http://archieves.eppo.int/EPPOStandards/diagnostic.htm). The most recent molecular tool (LAMP/ loop-mediated isothermal amplification method) has been proposed for very fast and reliable identification of thrips species in order to prevent the introduction of quarantine pests (Preybylska *et al*., 2015; Blaser *et al*.,2018).

Comments

This review has highlighted 15 sampling methods (table 1) which represent the most common described and used to sample thrips associated with the main colonized habitats. A few of these methods, such as sweep nets, beating, light traps, were built previously for other arthropods, but further studies and applications evolved to retain for some thrips peculiarities, i.e. phenotypic variations, life stages, within-plant distribution (Chu *et al*., 2006; Fedor *et al*., 2007; Reising *et al*., 2010). So that, the characteristics of each method recorded in this study can be considered as sampling strategies developed to provide the best evaluation of thrips species in different environments.

All the recorded methods have advantages and disadvantages (table 3) and the choice of the most suitable is related to the aim of a work plan, its costs and the time

Table 3. Brief descriptions of advantages and disadvantages shown by the main thrips sampling methods.

Sampling method	Advantages	Disadvantages
Soil set corers	Sampling thrips populations living in soil depth, for ecological studies in particular areas	Collecting only preimaginal thrips stages, intensive expensive labour
Berlese-Tullgren funnels	Collecting and evaluation of Arthropods fauna living in litter	Expensive labour, high costs to manage the equipment
Flotation	Sampling larvae and pupae of thrips from litter and soil, inexpensive method	Intensive labour to filter samples and separate specimens from residues
Emergence traps	Non- expensive equipment. Collecting adults thrips and others Insects emerging from soil	Expensive labour. Not useful method for collecting pupae or larvae
Screen traps	Collecting local populations of thrips and evaluation of biodiversity in undisturbed areas	Expensive labour
Beating	Collecting and counting of adults and larvae of a target thrips species	Expensive labour. Useful method only to sample thrips species infesting greenhouses crops
Sweep net	Non-expensive method, in field sampling and evaluation of fauna associated with area of vegetation	Intensive labour. Different ability in using the net can produce difficulties in comparing among samples
Binomial sampling	The evaluation of thresholds or density of a pest thrips species without requiring the complete counts of specimens in plants or in some plant structures	High costs could be due to the monitoring methods used
Direct counting	Field samplings assure that the species sampled are in the studied substrate. Both adults and larvae can be observed in flower samples	The method requires the removal of the whole plant from the soil, and it cannot be used for large plants
Turpentine funnel	A standardising method for samples of adult thrips and larvae from horticultural crops	Expensive labour. High costs to manage the equipment
Plant washing	The species studied is assured. Both adults and larvae can be collected	Intensive labour and costs
Suction traps	Monitoring of early abundance of thrips on vegetable crop. Also sampling for migration of populations of a species	High costs to manage the equipment
Sticky traps/ cards	Attractive (different colours attracting for diverse species), easy to deploy, collect and check	Traps/cards can be blown down by wind. Expensive method, only adults are caught
Water traps	Inexpensive methods; they can last for several seasons, easy to check	Intensive labour. Rain and irrigation can cause spill and specimens loss
Photoeclectors/light traps	They allow the collecting of bark-dwelling thrips populations in forest areas, also the monitoring of predatory and herbivores populations in a studied area	Intensive labour costs

required. Direct and absolute sampling methods such as beating on a plastic tray, sweep nets, direct counting and plant washes have the advantage to assure the researcher that the thrips species studied were in the sampled area or crop, and also to provide information on brachypterous and apterous specimens which cannot be caught on sticky traps. The beating method may remove both little arthropods and thrips from plants so that their abundance might be underestimated. Direct counts are largely used in ecological studies because these are less invasive methods. However, they are not reliable methods to sample plants or areas that host a rich thrips fauna with high distribution. In these cases, the identification of thrips species could be difficult owing to the great number of larval specimens. Furthermore, the method could be quite time consuming if the area contains large plants to be inspected. In forest habitats, where the fungus-feeders thrips exibit a criptic habit and show great dispersal ability to move between areas with scarce or abundant food, the screen traps represent a useful tool. Sticky and water traps are commonly used for collecting thrips from airborne populations. They provide information about the species composition of a studied area but are affected by the wind speeds. Moreover, they cannot be useful if the aim of sampling is to study the thrips associated with particular plant species, because the local population could include also thrips species from external areas.

Sometimes the species collected on sticky traps could not be associated to the plant from which they have been sampled. So, thrips caught in the traps might move from the surrounding fields, mainly during the spring season. The percentage of thrips damages has been recorded to be related to the monitoring processes, such as direct beating samplings, and not to sticky traps. For the agricultural pest monitoring, several authors suggest that data obtained have to be used carefully, as other factors might interfere. Finally, the active methods of collecting thrips from plants or wood are the most useful for taxonomic studies (Mound and Marullo, 1996). In fact, they provide accurate details on the origin of specimens and data referring to the description of thrips species and its biology.

Conclusions

The sampling methods examined have shown the main problems which are common to all studies on thrips biology, i.e. the difficulties to draft reliable strategies and the identification of thrips species. Any satisfactory sampling plan depends on the knowledge of the distribution of thrips both in space and time. Each species living on a plant or in a crop has its own distribution, biology, feeding preference. In the applied entomology projects, each pest thrips species needs the performing of several samplings and the comparing of different methods to make a good estimation of the thrips abundance in order to establish the economic thresholds to control them and to avoid the loss of production. Therefore, a sampling plan has to evaluate the economic damage levels associated with the pest thrips, the convenience of costs and the validation of the sampling methods. The identification of thrips species can be difficult for the presence of larval stages. Among them, only the second instar is usually used in a few available keys based on young specimens. The molecular identification could avoid such difficulty because the techniques involved utilize also DNA extraction from larvae, but their costs are high and the sequences available in GenBanks are referred to a low number of thrips species (Marullo *et al*., 2020).

Although this review has demonstrated the possible selection among 15 sampling methods for the main thrips habitats, however the control of pest species is based on their correct identification. The biology of a thrips and some morphological characters can change in different geographical areas (Silva *et al*., 2020). These changes might derive from the reproduction way producing different types which show series of interactions with other microarthropods, so that the sampling project conducted in different geographical areas might generate different results for the species collected and the sampling methods applied, especially to establish the abundance of thrips.

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