ORIGINAL PAPER

Larval and adult food preferences of the poinsettia thrips *Echinothrips americanus* Morgan, 1913 (Thysanoptera: Thripidae)

Lukáš Varga · Peter J. Fedor · Martin Suvák · Jozef Kiseľák · Ekrem Atakan

Abstract Numerous occurrence of *Echinothrips americanus* Morgan, 1913, a relatively newly established pest in European greenhouses, on a wide spectrum of cultivated plants throughout Slovakia has encouraged us to present current data on its food ecology. Analysing 1,650 plant species, the poinsettia thrips was found on 106 species (48 families) including 19 showing sporadic, 75 moderate and 17 high infestation. Larvae were detected on 25 plant taxa from 13 families, most of them being new hosts. Mature clusters of *Acalypha hispida*, showing moderate to high infestation level and carrying both larvae and adults, were selected for more detailed statistical evaluation. Preference of adults for upper and lower leaf surface tends to be without statistical significance, the larvae on the contrary were strongly related to the lower side (Pearson's $\chi^2 = 13.3552$, $P = 0.0013$). Concerning the age, increased occurrence was apparent on younger leaves for both larvae and adults. For larvae the nonparametric test gives the statistical difference between three age categories of leaves with the following values: Kruskal–Wallis $\chi^2 = 6.6384$, $P = 0.03618$. The statistical significance of age seems to be more crucial for younger shoots, as proved by the statistics for both larvae (Kruskal–Wallis $\chi^2 = 8.4852$, $P = 0.0144$) and adults (Kruskal–Wallis $\chi^2 = 7.1049$, $P = 0.0287$). Different food preferences of larvae and adults may result in specific approach when applying an effective biological or chemical control. Narrower tolerance of larvae could make them more manageable target in plant protection instead of efforts to control the whole thrips population.

Communicated by M. Traugott.

L. Varga (✉)
Department of Zoology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava, Slovakia
e-mail: varga.lukas@gmail.com

P. J. Fedor
Department of Ecosozology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava, Slovakia

M. Suvák
Botanical Garden of Pavol Jozef Šafárik University, Mánesova 23, 040 01 Košice, Slovakia

J. Kiseľák
Department of Mathematical Analysis and Numerical Mathematics, Faculty of Mathematics, Physics and Informatics, Comenius University, Mlynská dolina, 842 48 Bratislava, Slovakia

E. Atakan
Plant Protection Department, Faculty of Agriculture, University of Çukurova, Adana, Turkey

Introduction

The man-induced spread and establishment of alien plant pests becomes a serious problem in many countries at present (Smith et al. 2007; Kiritani and Yamamura 2003). Essential knowledge on their biological features and natural history belongs to the most important aspects contributing to effective control and prevention of threats resulting from non-native pest introductions. Regarding Thysanoptera as pests, one of the fundamental goals in recent phytoparasitology is to understand nutritional ecology of thrips in general and their interrelationships with host/feeding plants more deeply. These insects exhibit an

incredible diversity of feeding behaviour (Brodbeck et al. 2002). Concerning phytophagous species, including those of economic importance, surprisingly there is still a lack of data associated with their host plant range. Most of them, e.g. *Frankliniella occidentalis* (Pergande), *Thrips palmi* Karny or *T. tabaci* Lindeman (Thysanoptera: Thripidae) are considered as widely polyphagous (Pelikán 1989; Milne and Walter 1998; Jenser et al. 2006; Toapanta et al. 1996), although particular data on their host spectrum are often brief or general, indicating that little heed has been given to this particular matter. Moreover, the term "host-plant" is sometimes inaccurately generalized or misinterpreted as any plant from which adult specimens are collected (Marullo 2003).

Detailed information about morphology and ecology of *Echinothrips americanus* Morgan 1913 (Thysanoptera: Thripidae) have been reviewed before (Oetting and Beshear 1993; Trdan et al. 2003). The genetic structure based on the level of polymorphism of ITS1-5,8S-ITS2 region of the nuclear ribosomal DNA (rDNA) has been also studied (Trdan et al. 2003).

Echinothrips americanus, with a natural distribution in eastern North America (Vierbergen 1998; Mound and Marullo 1996), is a relatively newly established pest in European greenhouses. The first interception was made at Syon Butterfly House (Brentford, UK) in February 1989 (Collins 1998). It spread rapidly across Europe between 1995 and 2004, at present reported from at least 19 countries (Vierbergen et al. 2006; Varga and Fedor 2008).

In its original distribution area, it has been found to feed and reproduce on about 40 cultivated and 59 native plant species (Oetting et al. 1993), although only few of them were listed. In 1984 it was firstly noted as a pest of greenhouse plant *Euphorbia pulcherrima* (Oetting 1987), from which its common name, the poinsettia thrips, has been derived. The most comprehensive records on its host range included 44 plant taxa from 23 families (Vierbergen 1998).

However, the published data still lack deeper analyses on food ecology of this species. Taken together, numerous occurrence of *Echinothrips americanus* on a wide spectrum of greenhouse cultivated plants have encouraged us to (1) present current data on its host plant range distinguishing species with and without the larvae as well as (2) evaluate some aspects of trophic ecology including specific food preferences for both adults and larvae.

Materials and methods

The data presented here originate from research on pest thrips performed during the year 2008 on cultivated plants in various greenhouses throughout Slovakia. Specimens removed from the infested plant species were preserved in the AGA solution (10 units of 60 % ethyl alcohol, 1 unit of glycerine and 1 unit of glacial acetic acid), and were mounted onto microscope slides for identification according to the standard methods (Oetting et al. 1993; Mound and Kibby 1998). Detailed surveys of host plants were carried out in the Botanical garden in Košice from June to December 2008, where damage symptoms and infestation level were also estimated. This is the largest botanical garden providing the richest plant collections in Slovakia and it is actually the first locality in the country, where established population of *E. americanus* has been recorded. Moreover, environmentally friendly management tactics without use of pesticides, applied in the greenhouses, provide more suitable conditions for the research on food ecology of pest insects. Control surveys were performed in order to identify potentially new infested species among plant collections or presence of larvae on plants, on which they haven't been noted during previous inspections. At the first time it took several days to inspect all the plants carefully. The following checking observations were made in forenoon hours within the same day in 3 week periodicity, with at least 4 consequent observations made on each of the infested plant species, if the follow up was not possible during the whole investigation period due to significant phenological changes in particular plants or their (temporary) removal from expositions.

Thrips were counted on 10×10 cm (0.01 m^2) squares of leaf surface. This served for infestation level assessment which was arrayed in three categories that were supposed to correlate with the level of plant injury. Multiple squares (usually 5 to 10), depending on plant size, were inspected on individual plants to figure out their overall infestation. The number of plant specimens evaluated per species varied between 1–5, again with regard to plant size and their total number in the collections. Among plants with tiny leaves or bodies (e.g. some herbs), the inspected surface area had to be sometimes less than 0.01 m^2, then thrips abundance was converted to 0.01 m^2. The rest of above-ground parts of plants (stems, flowers etc.) were also tentatively checked, not to overlook any unusual spatial behaviour of this foliicolous pest.

Sporadic occurrence was assessed as 0.1 to 1 thrips specimen per 0.01 m^2 of the plant surface. Moderate infestation was classified as 1 to 5 specimens per 0.01 m^2, with almost all leaves occupied by at least one thrips. High infestation was assessed as more than five thrips specimens per 0.01 m^2.

Distribution and abundance of thrips on shoots and leaves of different age was evaluated by counting the thrips on younger and older shoots and leaves on the same plant taxon. For that aim, mature clusters of *Acalypha hispida*, showing moderate to high infestation level as well as

presence of larvae, were selected as a sampling material. The minimal number of leaves per shoot to be evaluated was 5. The species was grown in clumps, so the shoots were not attributed to certain plant specimen, but evaluated with regard to their age instead. In both groups of young (at the height of about 1.3 m) and older (about 0.8 m above ground) shoots, thrips were quantified on individual leaves (Fig. 1), which were numbered in order from the first—the youngest terminal leaf, to the lowest one, usually the 5th to 10th leaf downward the shoot spiral. Then the leaves were removed from shoots and scanned to calculate their surface area by the pixel number conversion to 1 cm^2. Thrips were visually counted prior to any manipulation with leaves to prevent their escape and then counted again under binocular stereomicroscope before the scanning process to include tiniest larvae. Specimens were counted separately for upper and lower leaf surface to prove any prospective preference.

In all statistical analyses the R software (2008) was chosen ($\alpha = 0.05$). Distinguishing the age of leaves 3 categories were established. Counting leaves downward from the shoot tips the first quartile was considered as young leaves, the middle two quartiles were proposed for middle age (mature) leaves, and the last quartile for old leaves. For testing the preference of leaf side several methods were applied according to their specific functions. Apart from the Pearson's chi-squared test (χ^2) of the null hypothesis that the joint distribution of the cell counts in a two-dimensional contingency table, the Fisher's exact test was used when sample size was too small. Analysing preference for the age of leaves the Kruskal–Wallis test (χ^2) comparing the medians of three or more groups and the non-parametric Wilcoxon–Mann–Whitney test (W) were selected.

Fig. 1 Leaf of infested *Acalypha hispida*, the plant used for detailed statistical analyses

Results

Totally 1,650 plant species belonging to 104 families and cultivated in the Košice Botanical Garden greenhouses were analysed. *E. americanus* was found on 106 of them (6.42% of the total plant taxa), from 48 different plant families. Infestation level varied among plant species, from sporadic (19 species) and moderate (75) to high (17), but with no regard to the particular family membership (Tables 1, 2 and 3). Among specimens of the same plant species it was relatively uniform, with only 5 species showing variance between the given levels (sporadic to moderate or moderate to high). *E. americanus* has not been observed in flowers, which were rather occupied by the western flower thrips *Frankliniella occidentalis*.

Regarding number of infested plant species, preference for Araceae, Acanthaceae, Euphorbiaceae, Fabaceae and Malvaceae was evident. Heavy damage was observed particularly on the group of *Acalypha hispida* bushes, of which the leaves were noted as drying out and falling down. High abundance of thrips was also recorded on *Hibiscus rosa-sinensis* where the damage has involved leaf-silvering and yellowing, deformation and eventually falling down under heavy infestation. In general plant injury symptoms correlated with thrips abundance categories, although *Sparmannia africana* showed only minimal damage despite supporting large numbers of thrips. Plants were disfigured by black faecal material on the leaf surface as well.

Larvae were detected on 25 plant taxa from 13 families (Table 4). Their presence did not correlate with the overall thrips population density as most of them were found on moderately infested plants (18 plant species). Another 6 species with high infestation and only 2 sporadically infested hosted larvae. Interestingly, the remaining 11 highly infested plant species (e.g. *Calla* sp.) did not show occurrence of larvae during the investigation period. Number of larvae in the samples was generally 5.17 times higher than number of adults on those plants bearing both of them.

Apart from few comose species holding trichomes on their leaves (e.g. *Actinidia chinensis*, *Cucumis sativus* or *Saintpaulia ionantha*), the thrips attacked almost exclusively plants with smooth simple medium or larger sized leaves. On one of them, *Acalypha hispida*, showing moderate to high infestation level as well as presence of larvae, preference for upper and lower leaf surface was studied. Total sample of 894 thrips was counted on scanned leaves. The larvae—adult ratio on different parts of plant varied from almost equal to significantly higher number of larvae (Table 5), whereas only 10.4% of thrips population has occurred on older shoots. The mean

Table 1 Plant taxa with sporadic infestation by *Echinothrips americanus* adults

Family	Host plant
Annonaceae	*Annona cherimola* P. Miller 1768
Araceae	*Dieffenbachia* Schott 1829 (Vierbergen 1998)*
Asteraceae	*Senecio petasites* (Sims) De Candolle 1838
	Stevia rebaudiana (Bertoni) Bertoni 1905
Caesalpiniaceae	*Delonix regia* (Bojer ex Hooker) Rafinesque-Schmaltz 1837
Celastraceae	*Catha edulis* (Vahl) Forsskål ex Endlicher 1841
Commelinaceae	*Tradescantia* Linnaeus 1753
Gesneriaceae	*Saintpaulia ionantha* H. Wendland 1893
Lomariopsidaceae	*Nephrolepis exaltata* (Linnaeus) Schott 1834
Moraceae	*Ficus benjamina* Linnaeus 1753
	Ficus salicifolia Vahl 1790
Musaceae	*Heliconia* Linnaeus 1753
	Musa Linnaeus 1753
Myrsinaceae	*Ardisia elliptica* Thunberg 1798
Nyctaginaceae	*Bougainvillea* Commerçon ex Jussieu 1789
Urticaceae	*Boehmeria nivea* (Linnaeus) Gaudichaud-Beaupré 1859
Zingiberaceae	*Curcuma longa* Linnaeus 1753

Asterisks represent references on formerly published data dealing with association of specific plant taxon with *E. americanus*

density of both larval and adult stage was 0.2377 specimens per cm^2 (0.0530 for adults and 0.1847 for larvae) on upper and 0.4591 (0.0600 for adults and 0.3991 for larvae) on lower side of the leaves.

Distribution of adults from this point of view tends to be accidental, with no statistically significant preference. Pearson's Chi-squared test of independence was applied with the result: $\chi^2 = 2.0755$, 2 degrees of freedom (df) and P value ($P = 0.3542$). Thus we do not reject the null hypothesis of statistical independence. Even when the age of shoots was distinguished the results declare no statistical difference (Fisher's exact test for older shoots: $P = 0.3717$, Pearson's Chi-squared test for younger shoots: $\chi^2 = 1.5391$, df = 2, $P = 0.4632$).

The larvae on the contrary were strongly related to the lower side. The statistics ($\chi^2 = 13.3552$, 2 df, $P = 0.0013$) have confirmed that frequency of appearance was dependent on the leaf's side. When distinguishing the age of shoots in evaluation, no statistical difference was observed for older shoots (Fisher's exact test: $P = 0.3955$), what on the contrary does not correspond with situation on younger shoots (Pearson's Chi-squared test: $\chi^2 = 9.5678$, df = 2, $P = 0.0084$).

Concerning *Acalypha hispida*, increased occurrence was apparent especially on younger leaves for both larvae and adults. For larvae the nonparametric test gives the statistical difference between three age groups with the following values: Kruskal–Wallis $\chi^2 = 6.6384$, df = 2, $P = 0.0362$. Sequentially, the exact Wilcoxon rank sum

test for each couple was calculated and only W = 62, $P = 0.0081$ gives the difference between the first and second category (W = 62, df = 2, $P = 0.0081$). For adults the situation is different, because the Kruskal–Wallis test has not confirmed any statistical significance of age (Kruskal–Wallis $\chi^2 = 2.8142$, df = 2, $P = 0.2449$). Thus no additional test was necessary.

The statistical significance of age seems to be more crucial for younger shoots, as proved by the statistics for both larvae (Kruskal–Wallis $\chi^2 = 8.4852$, df = 2, $P = 0.0144$) and adults (Kruskal–Wallis $\chi^2 = 7.1049$, df = 2, $P = 0.0287$). So presence of thrips simply depends on age of leaves. The Wilcoxon's test has confirmed the declared facts even more precisely: W = 9, $P = 0.0065$ (for larvae) and W = 12, $P = 0.0151$ (for adults). The statistical difference is apparent particularly for the first and second category and no other differences have been recorded.

For older shoots the analyses (Kruskal–Wallis $\chi^2 = 1.8491$, df = 2, $P = 0.3967$ larvae and Kruskal–Wallis $\chi^2 = 3.5346$, df = 2, $P = 0.1708$ for adults) do not reject null hypothesis, thus no additional testing was necessary.

The total mean density of *Echinothrips americanus* was calculated as 0.4558 (younger shoots) and 0.1151 (older shoots) thrips per cm^2. On younger shoots showing faster growth rate, the maximum density for both stages was found on the 4th–7th leaf, while on older, slowly growing shoots it was on the 4 youngest leaves. There was no apparent difference between distribution of adults and larvae in relation to age of leaves.

Table 2 Plant taxa with moderate infestation by *Echinothrips americanus* adults

Family	Host plant
Acanthaceae	*Pachystachys lutea* Nees 1847
	Ruellia Linnaeus 1753
	Sanchezia nobilis Hooker f. 1866
	Thunbergia coccinea Wallich ex D. Don 1825
Actinidiaceae	*Actinidia chinensis* Planchon, 1847
Apocynaceae	*Rauwolfia chinensis* Hemsley 1889
	Rauwolfia Linnaeus 1753
Araceae	*Aglaonema* Schott 1829
	Alocasia sanderiana W. Bull 1894
	Amorphophallus bulbifer (Roxburgh) Blume 1837
	Caladium Ventenat 1801
	Homalomena Schott 1832
	Philodendron Schott 1832
	Philodendron warszewiczii K. Koch & C.D. Bouché 1855
	Syngonium podophyllum Schott 1851
	Syngonium Schott 1829 (Vierbergen 1998)*
Asclepiadaceae	*Hoya* R. Brown 1810
Asparagaceae	*Asparagus falcatus* Linnaeus 1753
Bignoniaceae	*Tecoma capensis* (Thunberg) Lindley 1827
Caricaceae	*Carica* Linnaeus 1753
Celastraceae	*Euonymus* Linnaeus 1753
Dioscoreaceae	*Dioscorea sansibarensis* Pax 1892
Euphorbiaceae	*Euphorbia milii* Des Moulins 1826
	Euphorbia pulcherrima Willdenow ex Klotzsch 1834 (Oetting 1987)*
Fabaceae	*Bauhinia* Linnaeus 1753
	Erythrina rubrinervia Kunth 1824
	Strongylodon Vogel 1836
Gynkgoaceae	*Ginkgo biloba* (Linnaeus) Hoffmansegg 1771
Lythraceae	*Cuphea purpurea* Lemaire 1849
Malpighiaceae	*Galphimia glauca* Cavanilles 1799
	Malpighia coccigera Linnaeus 1753
Malvaceae	*Brachychiton acerifolius* (A. Cunningham ex G. Don) Macarthur 1855
	Brachychiton bidwillii Hooker 1859
	Hibiscus Linnaeus 1753
Mimosaceae	*Mimosa pudica* Linnaeus 1753 (Vierbergen 1998)*
Moraceae	*Ficus quercifolia* Roxburgh 1832
	Ficus triangularis Warburg 1894
Nymphaeaceae	*Nymphaea* Linnaeus 1753
Oxalidaceae	*Oxalis* Linnaeus 1753 (Oetting and Beshear 1993)*
Passifloraceae	*Passiflora caerulea* Linnaeus 1753
Phytolaccaceae	*Trichostigma peruvianum* (Moquin-Tandon) H. Walter 1909
Plumbaginaceae	*Plumbago auriculata* Lamarck 1786
Pontederiaceae	*Eichhornia crassipes* (Martius) Solms-Laubach 1883
Rubiaceae	*Gardenia volkensii* K. Schumann 1904
Rutaceae	*Murraya paniculata* (Linnaeus) Jack 1820
Salicaceae	*Salix* Linnaeus 1753
Sapindaceae	*Pappea capensis* Ecklon & Zeyher 1834
Solanaceae	*Solanum muricatum* Aiton 1789

Table 2 continued

Family	Host plant
Verbenaceae	*Clerodendrum* Linnaeus 1753
	Clerodendrum speciosum Dombrain 1869
	Clerodendrum thomsoniae Balfour 1862
Vitaceae	*Cissus* Linnaeus 1753
	Cissus antarctica Ventenat 1803
	Parthenocissus quinquefolia (Linnaeus) Planchon 1887
	Rhoicissus rhomboidea (E. Meyer ex Harvey) Planchon 1887
Zingiberaceae	*Hedychium gardnerianum* Shepard ex Ker-Gawler 1824
	Curcuma longa Linnaeus 1753

Asterisks represent references on formerly published data dealing with association of specific plant taxon with *E. americanus*

Table 3 Plant taxa with high infestation by *Echinothrips americanus* adults

Family	Host plant
Alstroemeriaceae	*Alstroemeria pulchella* Linnaeus f. 1782
Apocynaceae	*Rauwolfia* Linnaeus 1753
Araceae	*Calla* Linnaeus 1753
	Xanthosoma Schott, 1832
Balsaminaceae	*Impatiens* Linnaeus 1753 (Jacot-Guillarmod 1974; Vierbergen 1998)*
Bignoniaceae	*Parmentiera cereifera* Seemann 1841
Dioscoreaceae	*Dioscorea oppositifolia* Linnaeus 1753
Fabaceae	*Clitoria ternata* Linnaeus 1753
	Lablab purpureus (Linnaeus) Sweet 1826
Malvaceae	*Gossypium barbadense* Linnaeus 1753
Pontederiaceae	*Eichhornia crassipes* (Martius) Solms-Laubach 1883

Asterisks represent references on formerly published data dealing with association of specific plant taxon with *E. americanus*

Discussion

Echinothrips americanus was described originally from *Veratrum viride* in Florida, USA (Morgan 1913) and was not considered as a greenhouse pest until 1984. It has been recorded from about 50 species of cultivated plants in 24 families (Oetting et al. 1993; Vierbergen 1998). According to Collins (1998) it is reported to have a broad host plant range but there is a lack of detailed information in the literature. It causes damage to various ornamentals and even vegetables (pepper, cucumber) or other crops (Vierbergen 1998; Opit et al. 1997). However, the damage potential is generally not as significant as e.g. of *Thrips palmi* or *Frankliniella occidentalis*, the species response to common insecticides is satisfying as it does not develop resistance very quickly (Vierbergen et al. 2006; Oetting 1987; Trdan et al. 2003). In situations, when application of pesticides is undesirable and reliable methods of biological control are still not commercially available, the thrips may cause substantially higher losses. In our research, *E. americanus* was found on 106 plant taxa belonging to 48 families of the total number of about 1,650 plant species (in 104 families). But it has to be emphasized that this number involved even 624 species of Opuntiaceae and 209 species

and cultivars of Orchidaceae, with none of the species being attacked. In contrast to the latter, records on imported orchids were noted previously (Vierbergen 1998), although no specification to species level or association as host plants was given. Additional 41 plant taxa associated with *E. americanus* can be found in literature (Vierbergen 1998; Vierbergen et al. 2006; Łabanowski 2007; Collins 1998; Jacot-Guillarmod 1974; Oetting et al. 1993; Nakahara and Hilburn 1989; Karadjova and Krumov 2003). Among them, substantial number of taxa belongs to families Araceae, Rosaceae, Asteraceae and Fabaceae and they include also 16 families (e.g. Agavaceae, Betulaceae, Crassulaceae or Ericaceae), which were not confirmed by the results presented in this paper.

Eighty-nine plant taxa have shown significant to serious injury due to presence of thrips, corresponding to medium and high infestation level. In these plants, symptoms and feeding activity were apparent, indicating that occurrence of thrips on them was presumably not accidental. The remaining 16 species with sporadic infestation, inconspicuous symptoms and absence of larvae is much more difficult to conclude, whether they may be marked as feeding or even host plants, or they just provided shelter for resting adult thrips. Moreover, most of the sporadically infested

Table 4 Cultivated host plants ascertained for both larvae and adults of *Echinothrips americanus*

Family	Host plant	Infestation level
Acanthaceae	*Justicia carnea* Lindley 1831	Moderate
	Ruellia amoena Nees 1847	Moderate
	Thunbergia grandiflora Roxburgh ex Rottler 1814	High
Apocynaceae	*Plumeria* Linnaeus 1753	High
Araceae	*Alocasia macrorrhiza* (Linnaeus) G. Don 1839	Moderate
	Alocasia (Schott) G. Don 1839	Moderate
	Amorphophallus rivieri Durieu ex Carrière 1879	Moderate
	Amorphophallus Blume ex Decaisne 1834	High
	Zantedeschia aethiopica (Linnaeus) Sprengel 1826	High
	Nephthytis afzelii Schott 1857	Moderate to high
Araliaceae	*Hedera helix* Linnaeus 1753 (Łabanowski 2007)*	Moderate
Brassicaceae	*Anastatica hierochuntica* Linnaeus, 1753	Moderate
Caricaceae	*Carica pentagona* Heilborn 1922	Moderate
Euphorbiaceae	*Acalypha hispida* Burman f. 1768	Moderate
	Acalypha Linnaeus 1753	Moderate
	Codiaeum variegatum (Linnaeus) Blume 1824	Sporadic to moderate
	Manihot esculenta Crantz 1766	Moderate
Fabaceae	*Acacia visco* Lorentz ex Grisebach 1879	Sporadic
Malpighiaceae	*Malpighia glabra* Linnaeus 1753	Moderate
Malvaceae	*Gossypium hirsutum* Linnaeus 1753	Moderate
	Hibiscus rosa-sinensis Linnaeus 1753	Moderate
Passifloraceae	*Passiflora edulis* Sims 1818	Moderate
Tiliaceae	*Sparmannia africana* Linnaeus f. 1782	High
Vitaceae	*Cissus brevipedunculata* Maximowicz 1859	Moderate
	Cissus tweediana (Baker) Planchon 1887	Moderate

Asterisks represent references on formerly published data dealing with association of plant taxon with *E. americanus*

species do not belong to the preferred plant families, suggesting that *E. americanus* has occurred rather accidentally on most of these plants. The thrips has never been recorded feeding on coniferous woody plants before (Vierbergen 1998) and thus repeated detection of thrips feeding on gingko seedlings, followed by evident leaf injury, should be pointed out, although larvae have not been noted during a relatively short period, when young gingko plants were placed to overwinter in the greenhouses. This proves that coniferous plants can serve this species as a food source, at least for the adults.

According to the number of attacked species and thrips reproduction outcomes, families of Araceae, Acanthaceae,

Table 5 Larvae—adult ratio on different part of *Acalypha hispida*

	Upper leaf surface	Lower leaf surface	Both surfaces
Younger shoots	4.6949:1	8.7170:1	6.1518:1
Older shoots	1.1111:1	2.0833:1	1.8182:1

Euphorbiaceae, Fabaceae and Malvaceae belong to most preferred in the greenhouses. In its original distribution area the thrips is associated particularly with *Impatiens* spp. (Balsaminaceae) (Mound and Marullo 1996). The host plant range of *E. americanus* was supposed to be generally more similar to that of the members of subfamily Panchaetothripinae than Thripinae, where the thrips actually belongs (Trdan et al. 2003). This is partly true when considering only some of the most common greenhouse pest species from Panchaetothripinae, e.g. *Hercinothrips femoralis*, *Heliothrips haemorrhoidalis* or perhaps even *Parthenothrips dracenae* and especially their particular favour of Araceae. Panchaetothripinae show a variety of plant associations, with considerable number of species preferring grasses and others reported as mono-/oligophagous or seeming to have quite different host spectra comparing to *E. americanus* (Wilson 1975; Jacot-Guillarmod 1974). Contrary of the most common Thripinae (*Frankliniella occidentalis*, *Thrips tabaci*), *E. americanus* does appear as almost strictly foliicolous thrips, what is more often a feature of pests belonging to the subfamily Panchaetothripinae. However, *E. americanus* has been

frequently observed on the same plants together with *F. occidentalis* in the surveyed greenhouses, with the latter occurring rather in flowers of blossoming plants. The host spectrum of *F. occidentalis* is probably much wider and may include also most of the hosts of *E. americanus*, although few exceptions were noticed (e.g. *Hibiscus rosa-sinensis*), where *F. occidentalis* has never occurred.

Larvae were found on 23.58% species of the infested plants. All except one are new hosts for this thrips according to present data in literature. Their membership to 13 families indicates an overall wide host plant range. The fact that larvae were not detected on 11 of 17 highly infested plant species despite of repeated inspections may underline the hypothesis that adults actively migrate from their original host to colonize other plants or eventually that food preference of larvae and adults is not completely identical. This may be enabled by specific conditions present in surveyed greenhouses, where plants were grown in relatively high density and species richness, affording opportunity to readily migrate from one to another plant and select the preferred food source. In the investigated greenhouses, larvae were absent also on some commonly reported hosts, such as *Euphorbia pulcherrima*. The reason is difficult to justify, however the ability of maintaining thrips populations can vary even among different genotypes and phenotypes of single host plant species as proved by previous studies (Maris et al. 2004; Frei et al. 2004) and this is already used to select so called thrips-resistant plants in agriculture. Thrips behaviour on a host plant can be modified by numerous factors in general. Those features of thrips life history affected by photoperiod, which is often manipulated to grow crops, were experimentally put to trial (Whittaker and Kirk 2004). The amount of walking activity, pollen consumption and oviposition all increased with increasing photophase. Even growth and reproduction, which are of main interest in pest control, are affected beside temperature also by host plant characteristics as shown on *Thrips palmi* (Tsai et al. 1995). On the other hand, the cause of differences in larval and adult infestation of plant species may result also from endogenous factors (thrips themselves), as individual thrips specimens or even distinct thrips populations as well as specific developmental stages may show unlike preferences for certain plant taxa.

Preference for lower leaf side has been statistically proved only for larvae, while adults have shown indifferent association. There are more hypotheses, which could be suggested to explain different strategy of leaf surface exploitation by adults and larvae. Cuticle of larval stages is less sclerotized and larvae are generally less motile than adults, thus they tend to seek protection against predators and unfavourable meteorological conditions (rainfall, etc.). On the other hand, inconspicuous yellowish colour itself discriminates in favour of larvae regarding predation in

comparison to the easily distinguishable dark adults. The other hypothesis could emphasize the negative phototaxis of larvae, which therefore do not move to upper leaf surface in huge numbers. Morphological and physiological features of bifacial leaves may also play an important role. The lower (abaxial) epidermis of leaf has often thinner cuticle and less dense trichomes than upper (adaxial) epidermis providing better access to nourishing plant tissues also for weaker mouthparts of larvae. Furthermore, the lower spongy parenchyma has less chloroplasts and higher content of nutrient deposits (esp. starch and proteins) than upper palisade parenchyma (Fahn 1990; Evert 2006), which may promote larval development. Preference of the younger growth over older one may be due to mechanical (sclerotization of cuticle and cell walls, scarred tissue resulting from previous feeding activity) as well as physiological (accumulation of particular metabolites) differences between older and younger leaves. However, the first (1–2) terminal leaves hosted only few to zero thrips specimens, which made a statistical difference between the first and second category (the youngest an mature leaves). Thus, still young but already matured leaves with sufficient contents of substantial organics in the parenchyma cells are preferred by thrips. This is particularly apparent on younger shoots, where leaf development is faster and distinction among three categories of leaves in thrips density is more evident. Distribution on older shoots was more homogenous because of relative lack of new growth on shoot tips. But even here, the oldest leaves were avoided, possibly due to higher content of tannins and other repelling substances, lower rate of photosynthesis or less favourable mechanic features of plant tissues.

Although *E. americanus* has usually only minor damage potential in ornamental trade due to effective control by use of insecticides, it is often considered as successful opportunist or invader, which can become a problematic pest in greenhouses, where more environmentally acceptable means of pest control are being applied. Larvae and adults have been found feeding on plants belonging to many different taxonomic groups. The thrips is typically polyphagous, although many times the most infested plants are not those hosting larvae. More attention by performing the control activities should be therefore paid on plants with occurrence of larvae, which especially afford opportunity to maintain thrips population. Biological control of *E. americanus* is still rather under investigation similarly as with most other pest thrips, which are r-selected with population attributes that are believed to result in thrips outstripping the capacity of natural enemies to regulate thrips populations (Funderburk et al. 2000).

As a conclusion different food preferences of larvae and adults may result in specific approach when applying an effective biological or chemical control. Number of plant

taxa being attacked by adult *E.americanus* can be actually more than four times higher than that of plants supporting larvae. Thus larvae have probably much narrower host range and are more fastidious in comparison to adults, which on the other hand may choose plants for oviposition more carefully than those serving as a food source. In addition, larvae are strongly fixed to the lower side of leaves, although there was no significant difference between the stages in regard to proved preference of younger plant tissues. Supposedly narrower tolerance of larvae could make them more manageable target instead of efforts to control the whole thrips population.

References

Brodbeck BV, Funderburk J, Stavisky J, Andersen PC, Hulshof J (2002) Recent advances in the nutritional ecology of Thysanoptera, or the lack thereof. In: Marullo R, Mound LA (eds) Thrips and tospoviruses: Proceedings of the 7th international symposium on Thysanoptera, pp 145–153

Collins DW (1998) Recent interceptions of *Echinothrips americanus* Morgan (Thysanoptera: Thripidae) imported into England. Entomol Mon Mag 134:1–4

Evert RF (2006) Esau's plant anatomy: meristems, cells, and tissues of the plant body—their structure, function and development, 3rd edn. Wiley, New Jersey

Fahn A (1990) Plant anatomy, 4th edn. Pergamon Press, Oxford

Frei A, Bueno JM, Diaz-Montano J, Gu H, Cardona C, Dorn S (2004) Tolerance as a mechanism of resistance to *Thrips palmi* in common beans. Ent Exp Appl 112:73–80

Funderburk J, Stavinsky J, Olson S (2000) Predation of *Frankliniella occidentalis* (Thysanoptera: Thripidae) in field peppers by *Orius insidiosus* (Hemiptera: Anthocoridae). Environ Entomol 29(2): 376–382

Jacot-Guillarmod C (1970–1975) Catalogue of the Thysanoptera of the world. Ann Cape Prov Mus (Nat Hist) 7(1–4): 1–1255

Jenser G, Lipcsei S, Szénászi A, Hudák K (2006) Host range of the arrhenotokous populations of *Thrips tabaci* (Thysanoptera: Thripidae). Acta Phytopathol Entomol Hung 41(3–4):297–303

Karadjova O, Krumov V (2003) *Echinothrips americanus* Morgan (Thysanoptera: Thripidae), a new pest of the Bulgarian greenhouses. Proceedings of the international scientific conference "50 years University of Forestry", 1–2 April, Sofia, Bulgaria, pp 122–125

Kiritani K, Yamamura K (2003) Exotic insects and their pathways for invasion. In: Ruiz G, Carlton JT (eds) Invasive species: vectors and management strategies. Island Press, Washington DC, pp 44–67

Łabanowski G (2007) Poinsettia thrips (Echinothrips americanus Morgan)—occurrence in Poland and possibilities of control. Prog Plant Prot 47:289–302

Maris PC, Joosten NN, Goldbach RW, Peters D (2004) Decreased preference and reproduction, and increased mortality of *Frankliniella occidentalis* on thrips-resistant pepper plants. Entomol Exp Appl 113:149–155

Marullo R (2003) Host relationships at plant family level in *Dendrothrips* Uzel (Thysanoptera: Thripidae: Dendrothripinae) with a new Australian species. Aust J Entomol 42:46–50

Milne M, Walter GH (1998) Host species and plant part specificity of the polyphagous onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), in an Australian cotton-growing area. Aust J Entomol 37:115–119

Morgan AC (1913) New genera and species of Thysanoptera, with notes on distribution and food plants. Proc US Nat Mus 46:1–55

Mound LA, Kibby G (1998) Thysanoptera: an identification guide, 2nd edn. CABI, Oxford and New York

Mound LA, Marullo R (1996) The thrips of Central and South America: an introduction. Memoirs Entomol Int 6:1–488

Nakahara S, Hilburn DJ (1989) Annotated check list of the Thysanoptera of Bermuda. J N Y Entomol Soc 97:251–260

Oetting R (1987) Laboratory evaluation of the toxicity and residual activity of abamectin to *Echinothrips americanus*. J Agr Entomol 4(4):321–326

Oetting RD, Beshear RJ (1993) Biology of greenhouse pest *Echinothrips americanus* Morgan (Thysanoptera: Thripidae). Zool (J Pure Appl Zool) 4:307–315

Oetting RD, Beshear RJ, Liu T-X, Braman SK, Baker RJ (1993) Biology and identification of thrips in greenhouse ornamentals. Univ GA Agr Exp Stn Res Bull 414:1–20

Opit GP, Peterson B, Gillespie DR, Costello RA (1997) The life cycle and management of *Echinothrips americanus* (Thysanoptera: Thripidae). J Entomol Soc B C 94:3–6

Pelikán J (1989) A new imported pest of greenhouse plants, the western flower thrips, *Frankliniella occidentalis* (Pergande, 1895). Ochr Rostl 25(4):271–278

Smith RM, Baker RHA, Malumphy CP, Hockland S, Hammon RP, Ostojá-Starzewski JC, Collins DW (2007) Recent non-native invertebrate plant pest establishments in Great Britain: origins, pathways, and trends. Agr Forest Entomol 9:307–326

R software (2008-12-22) Version 2.8.1, The R Foundation for Statistical Computing, c/o Institut für Statistik und Wahrscheinlichkeitstheorie,Technische Universität Wien

Toapanta M, Funderburk J, Webb S, Chellemi D, Tsai J (1996) Abundance of *Frankliniella* spp. (Thysanoptera: Thripidae) on winter and spring host plants. Environ Entomol 25(4):793–800

Trdan S, Milevoj L, Raspudic E, Zezlina I (2003) The first record of *Echinothrips americanus* Morgan in Slovenia. Acta Phytopathol Entomol Hung 38:157–166

Tsai JH, Yue B, Webb SE, Funderburk JE, Hsu HT (1995) Effects of host plant and temperature on growth and reproduction of *Thrips palmi* (Thysanoptera: Thripidae). Environ Entomol 24(6):1598–1603

Varga L, Fedor P (2008) First interception of the greenhouse pest *Echinothrips americanus* Morgan, 1913 (Thysanoptera: Thripidae) in Slovakia. Plant Prot Sci 44(4):155–158

Vierbergen G (1998) *Echinothrips americanus* Morgan, a new thrips in Dutch greenhouses (Thysanoptera: Thripidae). Proc Sect Exp Appl Entomol Neth Entomol Soc 9:155–160

Vierbergen G, Cean M, Szellér IH, Jenser G, Masten T, Simala M (2006) Spread of two thrips pests in Europe: *Echinothrips americanus* and *Microcephalothrips abdominalis* (Thysanoptera: Thripidae). Acta Phytopathol Entomol Hung 41:287–296

Whittaker MS, Kirk WDJ (2004) The effect of photoperiod on walking, feeding, and oviposition in the western flower thrips. Entomol Exp Appl 111:209–214

Wilson TH (1975) A monograph of the subfamily Panchaetothripinae (Thysanoptera: Thripidae). Mem Am Entomol Inst 23: 1–354