



Thrips Vectors of Tospoviruses

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ABSTRACT. Tospoviruses belong to the sole phytovirus genus, *Tospovirus*, in the family *Bunyaviridae*. Tospoviruses are known to be exclusively transmitted by thrips belonging to the family Thripidae and subfamily Thripinae. Of the known 1,710 species of Thripidae only 14 thrips species are currently reported to transmit tospoviruses. Thrips-transmitted tospoviruses cause severe yield losses to several economically important crops in the United States and worldwide. For instance, a single *Tospovirus* (*Tomato spotted wilt virus*) alone caused an estimated \$1.4 billion in losses in the U.S. over 10 years. Global trade and associated movement of plant materials across borders have introduced tospoviruses and their vectors into newer areas. Advances in serological and molecular techniques have also led to identification of new tospoviruses. This scenario has also initiated new vector-pathogen interactions between introduced and native thrips species and tospoviruses. The goal of this manuscript is to provide a comprehensive and updated list of thrips species that serve as vectors of tospoviruses along with information pertaining to common names, key diagnostic characters, distribution, important crops economically affected, and thrips and *Tospovirus*-induced symptoms. The manuscript is prepared with special emphasis to the U.S., but information pertaining to other countries is also included.

Key Words: Thysanoptera; Thripidae; *Bunyaviridae*; transmission; vector-virus interactions

Thrips-transmitted tospoviruses (genus *Tospovirus*, family *Bunyaviridae*) are a major group of plant viruses affecting at least 1,090 host-plant species in 15 monocotyledonous and 69 dicotyledonous families worldwide (Parrella et al. 2003). So far, 20 *Tospovirus* species have been identified globally along with 14 thrips species in the family Thripidae that can serve as vectors (Ullman 1997, Jones 2005, Pappu et al. 2009, Ciuffo et al. 2010, Hassani-Mehraban et al. 2010). Prins and Goldbach (1998) estimated an annual loss worldwide of over \$1 billion from a single *Tospovirus*, *Tomato spotted wilt virus*. Based on 10 years of data from Georgia alone, we estimated annual average losses to be \$12.3 million in peanut, \$11.3 million in tobacco, and \$9 million in tomato and pepper for a total of \$326 million from 1996 to 2006. If the recent losses in Georgia were representative of the remaining United States peanut acreage and one-third of the remaining tobacco, pepper, and tomato acreage, a conservative loss was estimated at \$1.4 billion for the U.S. during this period. The purpose of this publication is to provide some basic biological information on thrips species in the U.S. and worldwide that are documented to transmit tospoviruses. Information pertaining to common names, key diagnostic characters, distribution, important crops economically affected, and thrips and *Tospovirus*-induced symptoms is included.

Thrips are known to transmit tospoviruses in a persistent propagative manner (Ullman et al. 1997). Both larval and adult stages of thrips vectors can actively feed on virus infected host plants, but only early larval instars can acquire the virus and later instar larvae and adults can transmit the virus after a latent period (Wijkamp et al. 1996a, Ullman et al. 1997, Whitfield et al. 2005, Persley et al. 2006). Adult thrips can acquire tospoviruses, but they do not transmit them. This is presumably because of insufficient multiplication in the midgut, a lack of movement to salivary glands, and a lack of multiplication thereafter. These are prerequisite for *Tospovirus* transmission (Wijkamp et al. 1996b). In addition, tospoviruses are not transmitted transovarially (Wijkamp et al. 1996a). Thus, each new generation of thrips vectors must acquire the virus as larvae. There are distinct associations between thrips species and their ability to transmit specific tospoviruses (Jones 2005). This article attempts to summarize these associations based on previous reviews and current literature.

Tospovirus infection is known to induce a suite of symptoms on its host plants including leaf speckling, mottling, chlorotic, and necrotic lesions of various shapes, sunken spots, etches, ring spots, stunting, yellowing, and wilting (Fig. 1a,b; *Tomato spotted wilt virus* symptoms on tomato foliage and fruit). These symptoms are known to vary with the host plant species, cultivars, plant age, virus isolate and/or strain, and environmental conditions (Best 1968, Lublinkoh and Foster 1977, Murai 2000, Chaisuekul et al. 2003, Gitaitis 2009). In addition to transmitting tospoviruses, thrips can also injure host plants by direct feeding. Thrips are known to feed by using their piercing and sucking mouth parts and consuming plant sap (Lewis 1973, Heming 1993). Such type of feeding often results in silvering and curling of leaves, followed by necrosis of plant tissue. Thrips feeding and oviposition can also result in injury to fruit (Childers and Achor 1995). Some thrips species (e.g., FL flower thrips, *Frankliniella bispinosa* (Morgan)), primarily feed on the floral parts such as petals and pollen, which results in spotting, deformation of flower buds, and reduced fruit set (Childers and Bullock 1999).

Before describing the thrips species and their *Tospovirus* associations, a brief general description of thrips, taxonomic characteristics used in thrips identification, and biology is provided. Thrips belong to the insect Order Thysanoptera (Mound 1997). The thrips species discussed in this article belong to the family Thripidae, and subfamily Thripinae (Mound and Ng 2009). Adult thrips are typically small (1–2 mm in length), slender insects, with two pairs of wings in the adult stage (Lewis 1973) (e.g., Fig. 2; western flower thrips, *Frankliniella occidentalis* (Pergande)). Adults of some species in this family can have a reduced wing (micropterous) form along with the winged (macropterous) form (e.g., tobacco thrips, *Frankliniella fusca* (Hinds)) (Lewis 1973, Oetting et al. 1993). The wings are long and narrow with a fringe of long hairs on both the front and hind wings (Fig. 3). This is why thrips are referred to as “fringe-wing” insects. The mouth cone is asymmetrical and is oriented posteriorly on the lower side of the head (Lewis 1973, Heming 1993). The antennae of Thripidae adults are filiform with 7–8 (rarely 6–9) segments of approximately equal size (Mound and Kibby 1998, Mound and Ng 2009). The glossary available online (http://keys.lucidcentral.org/keys/v3/thrips_of_california/data/key/thysanoptera/Media/Html/glossary/index.html) is interactive and illustrates in detail all of the important morphological characters in thrips by



Fig. 1. *Tomato spotted wilt virus* leaf symptoms in young tomato plants (a), *Tomato spotted wilt virus* induced irregular ripening on tomato fruit (b).

species (Hoddle et al. 2008). A current world checklist for Thysanoptera is also available (Mound 2010a).

The life cycle parameters of thrips are extremely variable from one species to another. Hence, as a general guide we discuss here the life history parameters of the most studied *Tospovirus* vector, *F. occidentalis*. Typically, *F. occidentalis* adults insert bean-shaped eggs into leaf, flower, or fruit tissues (Hansen et al. 2003). First instars hatch within 5 d and molt into second instars within a day at 30°C. Second instars develop into prepupae within 4–5 d (Lowry et al. 1992). Late second instars usually fall into the soil and pupate, but some can remain on the plant (Broadbent et al. 2003). The nonfeeding pupal stage is mostly immobile and has distinct and well-developed wing pads (Lewis 1973). Adults emerge within 3 d at 30°C (Lowry et al. 1992). Thrips development is known to be dependent on temperature. Adult females can survive for 4–5 wk at 30°C and oviposit ≈50 eggs (Reitz 2008).

Frankliniella occidentalis requires a minimum 194 degree days (minimum temperature 9.5°C) to complete a generation (Katayama 1997), but has been estimated to be as high as 254 degree days with a minimum temperature of 6.5°C (Lowry et al. 1992). Fertilized *F. occidentalis* females are known to produce female biased sex ratios and unmated *F. occidentalis* females are known to produce male biased sex ratios (Lewis 1973, Moritz 1997).

In the following section, information on thrips-*Tospovirus* associations will be summarized for each thrips species. We have also incorporated slide mount images of adults of each thrips species (except *Dictyothrips betae* that was unavailable) for a general reference. Though the images provide some of the taxonomic characteristics, the published keys of Thysanoptera would be needed to unambiguously identify thrips species. We encourage the readers to refer to the published keys (Mound et al. 1976, Mound and Marullo 1996,



Fig. 2. Western flower thrips.

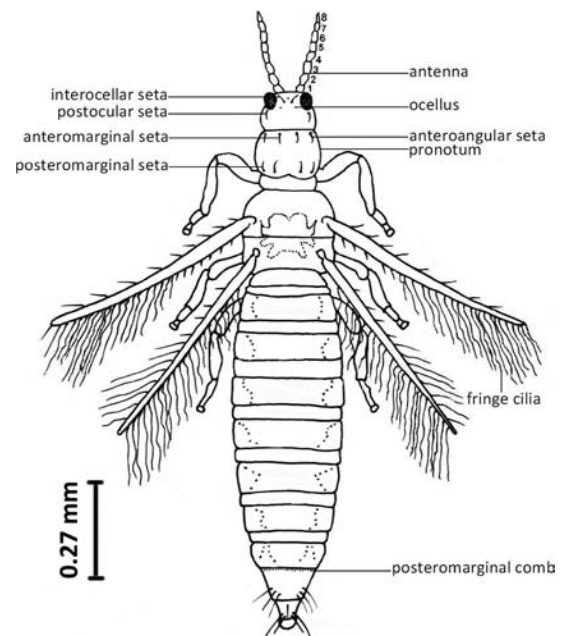


Fig. 3. Stylized drawing of *F. occidentalis*.

Mound and Kibby 1998, Mound and Masumoto 2005, Mound and Ng 2009) and software based identification keys (Moritz et al. 2001, Hoddle et al. 2008, Mound et al. 2009) for all identifications. The thrips species and *Tospovirus* associations presented in this publication have all been confirmed by published transmission studies (Table 1). The importance of thrips species that can serve as vectors of tospoviruses has been deduced based on the number of published

Table 1. Summary of thrips-*Tospovirus* associations that have been confirmed by transmission studies as of September 2010. The thrips species are ranked from highest to lowest based on the no. of virus associated publications currently available

Thrips species	<i>Tospovirus</i> transmitted	References on <i>Tospovirus</i> transmission
<i>Frankliniella occidentalis</i>	<i>Chrysanthemum stem necrosis virus</i>	Nagata and de Ávila 2000, Nagata et al. 2004
	<i>Groundnut ringspot virus</i>	Wijkamp et al. 1995, Nagata et al. 2004
	<i>Impatiens necrotic spot virus</i>	De Angelis et al. 1993, Wijkamp et al. 1995, Sakurai et al. 2004
	<i>Tomato chlorotic spot virus</i>	Nagata et al. 2004, Whitfield et al. 2005
	<i>Tomato spotted wilt virus</i>	Medeiros et al. 2004, Nagata et al. 2004, Wijkamp et al. 1995
<i>Thrips tabaci</i>	<i>Iris yellow spot virus</i>	Cortés et al. 1998, Hsu et al. 2010
	<i>Tomato spotted wilt virus</i>	Wijkamp et al. 1995
	<i>Tomato yellow fruit ring virus</i>	Golnaraghi et al. 2007
<i>Frankliniella schultzei</i>	<i>Chrysanthemum stem necrosis virus</i>	Nagata and de Ávila 2000, Nagata et al. 2004
	<i>Groundnut ringspot virus</i>	Wijkamp et al. 1995, de Bordón et al. 2006, Nagata et al. 2004
	<i>Groundnut bud necrosis virus</i>	Meena et al. 2005
	<i>Tomato chlorotic spot virus</i>	Wijkamp et al. 1995, Nagata et al. 2004
<i>Frankliniella fusca</i>	<i>Tomato spotted wilt virus</i>	Wijkamp et al. 1995, Sakimura 1969
	<i>Tomato spotted wilt virus</i>	Sakimura 1963 Naidu et al. 2001
<i>Thrips palmi</i>	<i>Calla lily chlorotic spot virus</i>	Chen et al. 2005
	<i>Groundnut bud necrosis virus</i>	Lakshmi et al. 1995, Meena et al. 2005, Reddy et al. 1992
	<i>Melon yellow spot virus</i>	Kato et al. 2000
	<i>Watermelon silver mottle virus</i>	Iwaki et al. 1984
	<i>Groundnut bud necrosis virus</i>	German et al. 1992, Meena et al. 2005
<i>Scirtothrips dorsalis</i> ^a	<i>Peanut chlorotic fan-spot virus</i>	Chen et al. 1996, Chu et al. 2001
	<i>Peanut yellow spot virus</i>	Gopal et al. 2010
	<i>Groundnut ringspot virus</i>	Wijkamp et al. 1995
<i>Frankliniella intonsa</i>	<i>Impatiens necrotic spot virus</i>	Sakurai et al. 2004
	<i>Tomato chlorotic spot virus</i>	Wijkamp et al. 1995
	<i>Tomato spotted wilt virus</i>	Wijkamp et al. 1995
	<i>Tomato spotted wilt virus</i>	Avila et al. 2006
<i>Frankliniella bispinosa</i>	<i>Tomato spotted wilt virus</i>	Tsuda et al. 1996
<i>Thrips setosus</i>	<i>Tomato spotted wilt virus</i>	Premachandra et al. 2005a,b
<i>Ceratothripoides claratris</i>	<i>Capsicum chlorosis virus</i>	Nakahara and Monteiro 1999
<i>Frankliniella zucchini</i>	<i>Zucchini lethal chlorosis virus</i>	de Bordón et al. 1999
<i>Frankliniella gemina</i>	<i>Tomato spotted wilt virus</i>	de Bordón et al. 1999
<i>Frankliniella cephalica</i>	<i>Groundnut ringspot virus</i>	Ohnishi et al. 2006
	<i>Tomato spotted wilt virus</i>	Ciuffo et al. 2010
<i>Dictyothrips betae</i>	<i>Polygonum ring spot virus</i>	

^aAmin et al. (1981) reported *S. dorsalis* as a vector for *Tomato spotted wilt virus*, but later German et al. (1992) clarified that this previous report of a Tomato spotted wilt virus-like virus in India based on a nonspecific identification was actually *Groundnut bud necrosis virus*.

papers (CAB Direct; accessed January 10, 2010 <http://www.cabdirect.org.proxy-remote.galib.uga.edu/>) that include the thrips species scientific name and the term “virus” for all publication categories. The search by thrips species yielded 412, 411, 105, 90, 82, 48, 21, 12, 10, 3, 3, 2, and 0 references. The thrips species are presented in the same order, respectively, as follows.

***Frankliniella occidentalis* (Pergande) (western flower thrips)**

Key Diagnostic Characters. Western flower thrips is yellow to brown with eight-antennal segments (Fig. 4). Pronotal anteromarginal



Fig. 4. *Frankliniella occidentalis*.

setae are equal in length to anteroangular setae and postocular seta IV is pronounced (Fig. 3). The tergite VIII comb is present and complete with long and irregular setae (Moritz et al. 2001, Mound et al. 2009) that are visible only under at least 100× magnification.

Distribution. *Frankliniella occidentalis* has a cosmopolitan distribution and it is also prevalent throughout the U.S. It is one of the most studied thrips species worldwide (Salguero Navas et al. 1991a,b; Kirk 2002; Groves et al. 2003; Kirk and Terry 2003; Reitz 2008, 2009). Its spread through international shipments of ornamental plants has been documented (Perrings et al. 2005).

Important Crops and Feeding Associated Injury. Western flower thrips attack at least 60 plant families that include important crop plants such as beans, cucumber, eggplant, lettuce, onion, pepper, tomatoes, watermelon, and ornamentals (Yudin et al. 1986). Western flower thrips primarily feed on the floral parts such as petals and pollen that results in spotting and deformation of flower buds. Even though they are prevalent in flowers (Riley and Batal 1998, Salguero Navas et al. 1991b), they can also be found on crop foliage (Todd et al. 1995, Joost and Riley 2004). In addition, thrips feeding can also cause fruit surface dimpling (Salguero Navas et al. 1991a).

***Tospoviruses* Transmitted.**

Chrysanthemum stem necrosis virus (Nagata and de Ávila 2000, Nagata et al. 2004).

Groundnut ringspot virus (Wijkamp et al. 1995, Nagata et al. 2004).

Impatiens necrotic spot virus (De Angelis et al. 1993, Wijkamp et al. 1995, Sakurai et al. 2004).

Tomato chlorotic spot virus (Nagata et al. 2004, Whitfield et al. 2005).

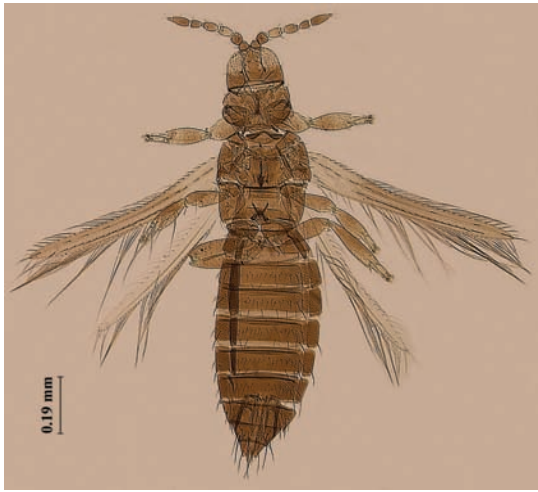


Fig. 5. *Thrips tabaci*.

Tomato spotted wilt virus (Medeiros et al. 2004, Nagata et al. 2004, Wijkamp et al. 1995).

Thrips tabaci Lindeman (onion thrips)

Key Diagnostic Characters. Onion thrips has seven-segmented antennae and do not possess elongated anterior setae on the pronotum (Fig. 5). The pleurotergites contain rows of fine microtrichia and are visible only under at least 100× magnification. They have gray pigmented ocelli in comparison to red pigmented ocelli in other thrips species (Moritz et al. 2001). The body color can vary with temperature from yellow to brown during development (Murai and Toda 2002).

Distribution. They are common throughout the U.S. (Diffie et al. 2008, Funderburk et al. 2007, Sparks et al. 2010). In addition, they are common in Africa, Australia, Central and South America, Asia, Europe, Mediterranean basin, and Canada (Mound 2007a).

Important Crops and Feeding Associated Injury. Onion thrips can infest plants belonging to ≈25 plant families, including Alliaceae. They are important pest of onions, garlic, ornamentals, and micro-propagated herbs, but they also occur on cotton, tomatoes, tobacco, and wheat (Mound 2007a). Onion thrips larvae actively feed on new foliage, but in onions tend to concentrate at the base of the leaves in the ‘neck’ region (Mo et al. 2008). In New York, 1–3 onion thrips larvae per leaf require control to prevent significant yield loss (Nault and Shelton 2010), thus very low numbers can cause damage to onions.

Tospoviruses Transmitted.

Iris yellow spot virus (Cortês et al. 1998, Hsu et al. 2010).

Tomato spotted wilt virus (Wijkamp et al. 1995).

Tomato yellow fruit ring virus (Golnaraghi et al. 2007).

Frankliniella schultzei (Trybom) (tomato thrips*, common blossom thrips* [*Not recognized as a common name by Entomological Society of America])

Key Diagnostic Characters. Tomato thrips occurs in two forms, pale (yellow with brownish blotches) and dark (dark brown) (Sakimura 1969). They have eight-segmented antennae (Fig. 6). Setae originate along the marginal line connecting the front edges of the two hind ocelli that is distinctly different for other dark *Frankliniella* species. Pronotal anteromarginal setae are shorter than anteroangular setae, and postocular setae IV are pronounced (Mound and Marullo 1996). The tergite VIII comb is absent.

Distribution. *Frankliniella schultzei* has been documented only in Florida in the U.S. (Diffie et al. 2008). It occurs in tropical and subtropical parts of the world (Vierbergen and Mantel 1991).

Important Crops and Feeding Associated Injury. *Frankliniella schultzei* attacks plants belonging to 35 families and 83 species in-

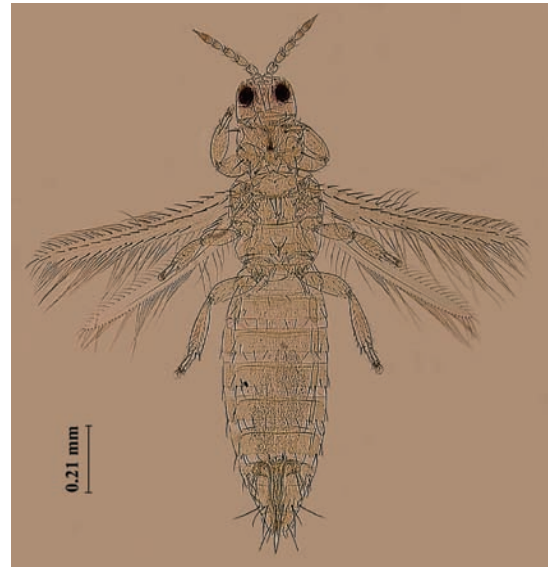


Fig. 6. *Frankliniella schultzei*.

cluding, peanuts, pepper, onions, tomatoes, and composite blooms (Palmer et al. 1989, Milne and Walter 2000). It has been reported to transmit five tospoviruses.

Tospoviruses Transmitted.

Chrysanthemum stem necrosis virus (Nagata and de Ávila 2000, Nagata et al. 2004).

Groundnut ringspot virus (Wijkamp et al. 1995, de Bordón et al. 2006, Nagata et al. 2004).

Groundnut bud necrosis virus (Meena et al. 2005).

Tomato chlorotic spot virus (Wijkamp et al. 1995, Nagata et al. 2004).

Tomato spotted wilt virus (Wijkamp et al. 1995, Sakimura 1969).

Frankliniella fusca (Hinds) (tobacco thrips)

Key Diagnostic Characters. Typically, tobacco thrips is brown with eight-segmented antennae (Fig. 7). Pronotal anteromarginal setae are shorter than anteroangular setae and postocular seta IV is reduced or absent. The comb on tergite VIII is absent in tobacco thrips (Moritz et al. 2001, Mound et al. 2009). Tobacco thrips can have a reduced wing (micropterous) form along with the winged (macropterous) form (Oetting et al. 1993).



Fig. 7. *Frankliniella fusca*.



Fig. 8. *Thrips palmi*.

Distribution. Tobacco thrips is very common in the southeastern U.S. (Diffie et al. 2008) and has been reported from all other states in the continental U.S. (Hoddle et al. 2008). It has also been studied in laboratories in The Netherlands and recently reported in Japan (Nakao et al. 2010).

Important Crops and Feeding Associated Injury. The tobacco thrips is known to feed on many weeds and economically important crops in the southeast (Salguero Navas et al. 1991b; Lowry et al. 1992; Oetting et al. 1993; Todd et al. 1995; Riley and Batal 1998; Groves et al. 2003; Hansen et al. 2003; Joost and Riley 2004, 2008; Riley and Pappu 2004). They are commonly found in peanut (Todd et al. 1995), tomato (Salguero Navas et al. 1991b, Riley and Batal 1998), cotton (DuRant et al. 1994, Groves et al. 2003), and onion (Riley and Batal 1998, Sparks et al. 2010). Tobacco thrips primarily feed on the foliage, preferring young leaves over older tissue (Joost and Riley 2008). Their feeding induces scarring and, in severe cases, results in distortion of leaves or stunting of the plant. In the southeastern U.S., this species is the earliest invader of crops planted in the spring (Todd et al. 1995, Joost and Riley 2004), and therefore has been associated with the greatest amount of yield loss because of the primary spread of *Tomato spotted wilt virus* in the field (Riley and Pappu 2004).

Tospoviruses Transmitted.

Tomato spotted wilt virus (Sakimura 1963).

Impatiens necrotic spot virus (Naidu et al. 2001).

Thrips palmi (Karny) (Melon thrips*)

Key Diagnostic Characters. Melon thrips are yellow and possess seven-segmented antennae (Fig. 8). It does not possess elongated anterior setae on the pronotum, but has two pairs of long posteroangular setae. The presence and location of the setae within triangular formation of ocelli and color distinguishes *T. palmi* from *T. tabaci*. Setae originate within the triangular area and ocelli have red pigment in *T. palmi*, whereas in *T. tabaci*, a pair of setae arises from the regions outside the triangular area and ocelli have gray pigment (Mound 2010b).

Distribution. *Thrips palmi* has been found in Hawaii and Florida especially during spring and summer. Interestingly, it has not been reported from elsewhere in the U.S. (Wang and Chu 1986). However, it is found in Africa, Australia, Central and South America, and South and South-East Asia (Mound 2010b).

Important Crops and Feeding Associated Injury. *Thrips palmi* is an important pest in ≈20 plant families including Cucurbitaceae and Solanaceae. *Thrips palmi* is known to feed on chili and sweet pepper, cucumber, eggplant, melon, potato, pumpkin, squash, and watermelon. It causes severe damage in many subtropical areas both through direct damage and virus transmission (Wang and Chu 1986).

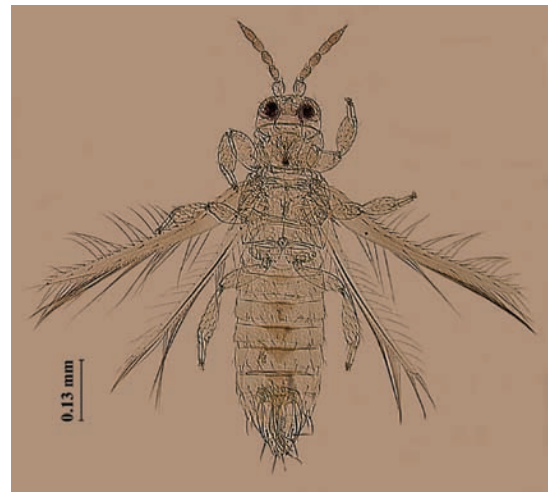


Fig. 9. *Scirtothrips dorsalis*.

Tospoviruses Transmitted.

Calla lily chlorotic spot virus (Chen et al. 2005).

Groundnut bud necrosis virus (Lakshmi et al. 1995, Meena et al. 2005, Reddy et al. 1992).

Melon yellow spot virus (Kato et al. 2000).

Watermelon silver mottle virus (Iwaki et al. 1984).

Scirtothrips dorsalis (Hood) (Chilli thrips*, yellow tea thrips*, castor thrips*, Assam thrips*, strawberry thrips*, oriental tea thrips*)

Key Diagnostic Characters. Chilli thrips is small (0.7 mm) with eight-antennal segments where the first two segments are pale-colored while the rest are relatively dark-colored. Posterior fringe cilia on fore wings are straight (Fig. 9). The center of the tergites and sternites contain dark pigmented areas (Moritz et al. 2001).

Distribution. *Scirtothrips dorsalis* has been reported in Florida and Hawaii and more recently noted in southern Georgia (Diffie et al. 2008), Florida (Edwards and Hodges 2010), and Texas (Osborne and Ludwig 2007). Besides the U.S., it has been found in Asia, Australia, South and South-East Asia (Chu et al. 2001, Mound 2007b) and recently in Israel (Hoddle et al. 2008).

Important Crops and Feeding Associated Injury. *Scirtothrips dorsalis* is a serious pest of 150 plant species in 40 families including cut flowers, fruits, and vegetables. *Scirtothrips dorsalis* feeding injury results in scarring of all above ground parts of the plant (Osborne and Ludwig 2007).

Tospoviruses Transmitted. Previously, Amin et al. (1981) reported *S. dorsalis* as a vector for *Tomato spotted wilt virus*, but later German et al. (1992) clarified that this previous report of a *Tomato spotted wilt virus*-like virus in India based on a nonspecific identification was actually *Groundnut bud necrosis virus*.

Groundnut bud necrosis virus (German et al. 1992, Meena et al. 2005).

Peanut chlorotic fan-spot virus (Chen et al. 1996, Chu et al. 2001).

Peanut yellow spot virus (Gopal et al. 2010).

Frankliniella intonsa (Trybom) (Eurasian flower thrips*, Eastern flower thrips*)

Key Diagnostic Characters. Typically, Eurasian flower thrips is brown with eight-segmented antennae (Fig. 10). The pronotal antero-marginal setae are shorter than anteroangular setae, and postocular seta IV is reduced. The comb on tergite VIII is similar to *F. occidentalis* (Moritz et al. 2001, Mound 2006a).

Distribution. *Frankliniella intonsa* has been recently recorded in the U.S. (Washington) and Canada (British Columbia) (Nakahara and Footitt 2007). It has also been reported from Europe and South-East Asia, specifically, Vietnam, Japan, and Taiwan (Mound 2010a).



Fig. 10. *Frankliniella intonsa*.

Important Crops and Feeding Associated Injury. *Frankliniella intonsa* is a pest of cotton, fresh flowers, bush beans, vegetable, and other horticultural crops (Moritz et al. 2001, Nakahara and Footitt 2007).

Tospoviruses Transmitted.

- Groundnut ringspot virus* (Wijkamp et al. 1995).
- Impatiens necrotic spot virus* (Sakurai et al. 2004).
- Tomato chlorotic spot virus* (Wijkamp et al. 1995).
- Tomato spotted wilt virus* (Wijkamp et al. 1995).

Frankliniella bispinosa (Morgan) (Florida flower thrips*)

Key Diagnostic Characters. Florida flower thrips is yellow with eight-segmented antennae (Fig. 11). Pronotal anteromarginal setae are shorter than anteroangular setae and the postocular seta IV is reduced compared with western flower thrips. “Spine like” setae at the apex of the second antennal segments are enlarged (Mound 2006b).

Distribution. This thrips species has been reported in Florida, Alabama, and southern Georgia (Diffie et al. 2008, Funderburk et al. 2007). It is also found in the Bahama Islands (Hoddle et al. 2008).

Important Crops and Feeding Associated Injury. Feeding by *F. bispinosa* induces reduced fruit set in citrus (Childers and Bullock 1999, Childers and Nakahara 2006). *Frankliniella bispinosa* can also attack tomato, pepper, eggplant, potato, tomatillo, cucumber, watermelon, squash, beans, sweet corn, citrus, and avocado (Frantz and Mellinger 1990). These flower thrips are attracted to white or yellow

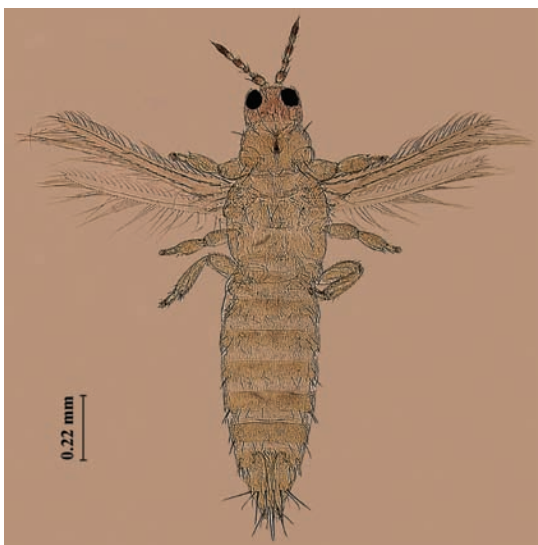


Fig. 11. *Frankliniella bispinosa*.



Fig. 12. *Thrips setosus*.

flowers, such as those of chrysanthemum and tomato and can occur in relatively high numbers compared with other flower inhabiting thrips species in Florida (Frantz and Mellinger 1990).

Tospovirus Transmitted. *Tomato spotted wilt virus* (Avila et al. 2006).

Thrips setosus (Moulton) (Japanese flower thrips*)

Key Diagnostic Characters. Japanese flower thrips is brown with seven-segmented antennae (Fig. 12). It has two pairs of long posteroangular setae (Moritz et al. 2001). The posterior margin of tergite VIII has a complete row of long and irregular microtrichia.

Distribution. *Thrips setosus* has not been documented in the U.S., but it has been found in Japan (Mound 2007c).

Important Crops and Feeding Associated Injury. *Thrips setosus* is a pest of tomato and tobacco in the fore mentioned regions (Mound 2007c).

Tospovirus Transmitted. *Tomato spotted wilt virus* (Tsuda et al. 1996).

Ceratothripoides claratris (Shumsher) (Oriental tomato thrips*)

Key Diagnostic Characters. The oriental tomato thrips is brown with eight-segmented antennae (Fig. 13). It has two pairs of posteroangular setae on the pronotum. The tergite VIII comb is complete with long microtrichia (Mound 2005, Mound and Nickle 2009).



Fig. 13. *Ceratothripoides claratris*.

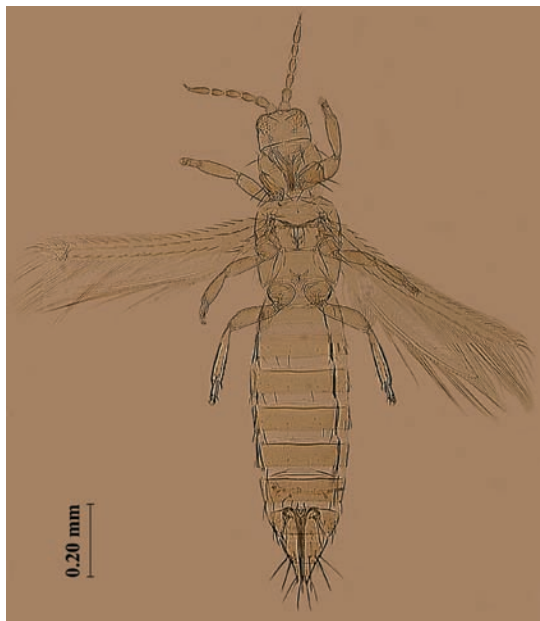


Fig. 14. *Frankliniella zucchini*.

Distribution. This thrips species has not been documented in the U.S., but it has been found in South and South-East Asia (Mound 2005).

Important Crops and Feeding Associated Injury. *Ceratothripoides claratris* is the most prevalent pest thrips species of tomato in Thailand. It is known to feed on the foliage, stems, and fruits. Oviposition by females on fruits leads to scarification and malformation of tomatoes (Premachandra et al. 2005a).

Tospovirus Transmitted. *Capsicum chlorosis virus* (Premachandra et al. 2005a,b).

Frankliniella zucchini (Nakahara & Monteiro)

Key Diagnostic Characters. *Frankliniella zucchini* adults are yellow to brown with eight-segmented antennae (Fig. 14). Pronotal anteromarginal setae are equal in length to anteroangular setae, and postocular seta IV is pronounced. The tergite VIII comb is present and complete with long, regular setae (Moritz et al. 2001).

Distribution. *Frankliniella zucchini* has not been reported from the U.S. It was initially reported from Brazil, South America (Moritz et al. 2001).

Important Crops and Feeding Associated Injury. *Frankliniella zucchini* is reported as a pest of zucchini (*Cucurbita pepo* L.) and other cucurbits such as watermelon and cucumber. They feed mainly on foliage and flowers of these crops (Nagata et al. 1998, Nakahara and Monteiro 1999).

Tospovirus Transmitted. *Zucchini lethal chlorosis virus* (Nakahara and Monteiro 1999).

Frankliniella gemina (Bagnall)

Key Diagnostic Characters. *Frankliniella gemina* is yellow with eight-segmented antennae (Fig. 15). The pronotal anteromarginal setae are approximately equal in length to anteroangular setae (as in Fig. 3). The postocular seta IV is long (Moritz et al. 2001). The comb on tergite VII is complete with regularly spaced microtrichia.

Distribution. *Frankliniella gemina* is documented from the Parque Estadual de Itapuã and Gaúcho Highlands region of Brazil (Adriano et al. 2006; Carrizo et al. 2008; Pinent et al. 2006, 2007) and from Mendoza, Argentina (de Bordon et al. 1999).

Important Crops and Feeding Associated Injury. This thrips species is known to feed on flowers of various plant species including avocado, tomato, alfalfa, and lettuce (de Bordon et al. 1999, Hoddle et al. 2002, and Pinent et al. 2006).



Fig. 15. *Frankliniella gemina*.

Frankliniella gemina has also been found feeding on strawberries (Pinent et al. 2007).

Tospoviruses Transmitted.

Tomato spotted wilt virus (de Bordon et al. 1999).

Groundnut ringspot virus (de Bordon et al. 1999).

Frankliniella cephalica (Crawford) (Florida flower thrips*)

Key Diagnostic Characters. Adult thrips of this species are typically yellow with eight-segmented antennae (Fig. 16). Pronotal anteromarginal setae are shorter than anteroangular setae, and postocular seta IV is reduced (Mound and Marullo 1996). The comb on tergite VIII is absent medially.

Distribution. It is from Mexico and the Caribbean (Mound 2010a) and was documented in Ryukyu Island southwest of Japan (Masumoto and Okajima 2004). It is also reported from Florida (Diffie et al. 2008).

Important Crops and Feeding Associated Injury. *Frankliniella cephalica* was found on *Bidens pilosa*, *Ipomoea batatas* (L.), tomato,



Fig. 16. *Frankliniella cephalica*.

mangrove, and citrus (Frantz and Mellinger 1990, Masumoto and Okajima 2004, Childers and Nakahara 2006).

Tospovirus Transmitted. *Tomato spotted wilt virus* (Ohnishi et al. 2006).

Dictyothrips betae (Uzel)

Key Diagnostic Characters. *Dictyothrips betae* has a reticulated yellow body 0.8 mm in length with a slight reddish tinge on the thorax. Antennae are multicolored and eight-segmented, segments I and II are yellow, segments III-V are basally yellow and apically brown, and segments VI-VIII are brown. The prothorax has no long setae (Priesner 1928).

Distribution. *Dictyothrips betae* has only been found in palearctic countries, namely Czechoslovakia, Hungary, Romania, USSR, Ukraine (Bhatti 1978), Germany (Raehle 1974), The Netherlands, and in Italy (Franssen and Mantel 1992, Marullo and Strassen Zur 2003, Strassen Zur 2007).

Important Crops and Feeding Associated Injury. *Dictyothrips betae* has been reported on sugar beet (Priesner 1928) and transmission studies were conducted on *Polygonum convolvulus* and *Polygonum dumetorum* (Ciuffo et al. 2008, Ciuffo et al. 2010).

Tospovirus Transmitted. *Polygonum ring spot virus* (Ciuffo et al. 2010).

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