CAPS Datasheets provide pest-specific information to support planning and completing early detection surveys.

Tobamovirus Tomato brown rugose fruit virus (Salem et al., 2016)

Figure 1. Infected tomato fruits can be rough, deformed, brown, necrotic, and wrinkled, while leaves are mottled or mosaic (Dr. José Antonio Garzón Tiznado, Universidad Autónoma de Sinaloa-México).

Synonym(s):
None

Common Name
Tomato brown rugose fruit virus
ToBRFV

Type of Pest
Virus

Taxonomic Position
Class: Not assigned,
Order: Not assigned,
Family: Virgaviridae

Reason for Inclusion in Manual
CAPS Solanaceous Host Commodity Survey list, 2021-present

Pest Recognition
This section describes characteristics of the organism and symptoms that will help surveyors recognize possible infestations/infections in the field, select survey sites, and collect symptomatic material. For morphological descriptions, see the Identification/Diagnostic resources on the Approved Methods for Pest Surveillance (AMPS) pest page on the CAPS Resource and Collaboration website.

Pest Description
There are no visible morphological or behavioral characteristics for this organism in the field.

Damage/Symptoms
Surveyors should look for visual symptoms of tomato brown rugose fruit virus (ToBRFV) infection in the field. In tomato plants, symptoms appear as early as 10-14 days after infection (Luria et al., 2017) and may not appear for up to 30 days (Panno et al., 2019b). Some infected plants are asymptomatic (ASTA, 2019). The severity and prevalence of symptoms vary with the age of the plant (DeRuiter, 2019). Plants that are younger at the time of infection exhibit the most severe symptoms (DeRuiter, 2019). Different tomato varieties can have varying symptom expression (Luria et al., 2017). Symptom expression is also influenced by growing conditions (light and temperature), nutritional status, and fruit load (DeRuiter, 2019).

Symptoms of ToBRFV infection in tomato leaves include chlorosis, mosaic, mottling, leaf distortion, and possible leaf narrowing (Figs. 1-2) (Cambron-Crisantos et al., 2018; Luria et al.,

Figure 2. Naturally infected tomato plants. (**A-C**) Symptomatic mosaic pattern on leaves of cluster tomato plants cv. Mose. (**C**) Narrowing leaves of cluster tomato plants. (**D**) Dried peduncles and calyces on cherry tomato plants cv. Shiran leading to fruit abscission. (**E**) Necrotic symptoms on pedicle, calyces and petioles cv. Ikram. (**F**) Typical fruit symptoms with yellow spots cv. Mose. (**G-I**) Variable symptoms of tomato fruits cv. Odelia. (**G**) The typical disease symptoms. (**H**) Symptoms of mixed infections by the abundant Tomato spotted wilt virus (TSWV) and the new tobamovirus isolate. (**I**) Unique symptoms of the new tobamovirus isolate found at a single location at Sde-Nitzan village.

2017). Infected calyces, peduncle, sepals, and petioles may also develop necrotic spots that can lead to premature fruit drop (Fig. 2) (Davino, 2019b, Fidan et al., 2019 Luria et al., 2017). Stems can also show signs of necrosis (Davino, 2019a, 2019b) (Fig. 1, 3).

Infected tomato fruit exhibits yellow and brown discoloration, grooves, deformation, necrosis, and rugosity (Fig. 1, 2) (Cambron-Crisantos et al., 2018; Fidan et al., 2019; Luria et al., 2017; Panno et al., 2019; Salem et al., 2016). The size and number of tomato fruit produced are reduced (ASTA, 2019). In pepper, infected fruits display similar symptoms (Fig. 4) but can also show green grooves (Cambron-Crisantos et al., 2018).

Figure 3. Pepper plants harboring *L1*,*3*,*4* hypersensitivity response (HR) to infection by ToBRFV isolate. **(A-D)** Symptoms developed following sap-mechanical leaves inoculation showing **(A)** necrotic lesions; **(B)** yellowing; **(C, D)** dried apoptotic leaves. **(E-G)** HR symptoms developed following root inoculation demonstrating dried spots on stems leading to plant growth inhibition.

Easily Mistaken Species

ToBRFV cannot be visually distinguished from other plant pathogens or abiotic symptoms. Molecular identification is necessary to confirm the presence of ToBRFV. Numerous tobamoviruses are present in the United States and can infect tomato and/or pepper. Some of these viruses include: pepper mild mottle virus (PMMoV), tobacco mosaic virus (TMV), tomato mosaic virus (ToMV), tomato mottle mosaic virus (ToMMV), and tomato spotted wilt virus (TSWV) (Baker and Adkins, 2000). Symptoms presented by these viruses are usually similar to those of ToBRFV (Dey, 2019).

Biology and Ecology

Tobamoviruses are rigid rod-shaped plant viruses that are very easily transmitted by mechanical inoculation or contact with infected plants (Baker and Adkins, 2000). Tobamoviruses are stable and may remain infective in seed, plant residue, farm equipment, and soil for long periods of time (Broadbent, 1976; Dombrovsky and Smith, 2017; Panno et al., 2019). ToBRFV may be transmitted mechanically through contaminated tools, equipment, clothing, workers' hands, plant to plant contact, and crop debris in soil (Broadbent, 1976; Broadbent and Fletcher, 1963; Dey, 2019). Tobamoviruses are also known to spread through contaminated propagation materials and in irrigation water (Broadbent and Fletcher, 1963; Dey, 2019; Smith and Dombrovsky, 2019). Infected seed coats attached to young plants (7-14 days old) can increase

transmission of the virus between plants during transplanting of the seedlings (Broadbent, 1965). Infected tomato fruit can serve as an inoculum for spread of ToBRFV to tomato plants (Klap et al., 2020).

Volunteer plants may serve as reservoir hosts for tobamoviruses and facilitate spread. ToBRFV has been detected in a wild solanaceous host, *Physalis angulate* (cutleaf groundcherry) (Miss, 2019; NCBI, 2019), and mechanically inoculated into another wild host, *Solanum nigrum* (black nightshade) (Luria et al., 2017). Tobamoviruses are known to overwinter in weed hosts, which may serve as inoculum for crop hosts in consecutive growing seasons (Smith and Dombrovsky, 2019).

Transmission of ToBRFV can also occur through movement of pollen by the bumble bee *Bombus terrestris* in Europe (Levitzky et al., 2019). In the United States, a different bumble bee species, *Bombus impatiens*, is mass-reared as a pollinator of tomato and has been shown to vector the *Pepino mosaic virus* between tomato plants (Shipp et al., 2008) and between tomato and nightshade (Stobbs and Greig, 2014). Additional research is needed to determine whether *B. impatiens* or other pollinators in the United States can spread the virus.

Figure 4. Pepper fruits with yellow blotching due to ToBRFV (Raed Alkowni, An-Najah National University)

Known Hosts

ToBRFV is known to infect plants in the family Solanaceae, and the most economically important hosts are tomato and pepper (Salem et al., 2020; Salem et al., 2016). In addition, numerous other solanaceous plants can be experimentally infected by the virus (Luria et al., 2017). This virus was described in 2015 (Salem et al., 2016), so the full host range may not be well-understood. All known hosts of ToBRFV are present in the United States (Kartesz, 2015).

The host list below includes cultivated and wild plants that 1) are infected or infested by the pest under natural conditions, 2) are frequently described as major, primary, or preferred hosts, and 3) have primary evidence for damage documented in the literature. Economically important plants are highlighted in bold.

Preferred hosts

***Capsicum annum* (sweet pepper)**, ***Solanum lycopersicum* (tomato),** (NCBI, 2019; Salem et al., 2020; Salem et al., 2016).

Other hosts

Capsicum spp. (Pepper), *Physalis angulata* (cutleaf groundcherry) (Miss, 2019; NCBI, 2019; Salem et al., 2020).

A positive test result for ToBRFV in *Solanum melongena* (eggplant) was reported in Mexico in 2018 (Miss, 2019). However, eggplant is reported to not be a host of ToBRFV in two other research studies (Luria et al., 2017; Panno et al., 2019b).

Pest Importance

Tobamoviruses are easily transmitted through agricultural systems and difficult to control (Baker and Adkins, 2000), and ToBRFV is causing global concern for the tomato industry (Hak and Spiegelman, 2019; Ling et al., 2019). Fruit that has been infected by this virus is often unmarketable due to discoloration or disfigurement (ASTA, 2019), and tomato yield losses of 30-70% due to ToBRFV have been reported (Dey, 2019). At this time, ToBRFV resistance is not available in tomato production (ASTA, 2019). The Tm-2^2 gene that is used to confer resistance to other tobamoviruses in tomato is not effective against ToBRFV (Fidan et al., 2019; Luria et al., 2017). New control measures such as breeding for resistance, additional seed/transplant screening, and additional sanitation measures in the United States may be necessary to control this virus.

A survey in Sicily found ToBRFV in seed lots, nurseries, and greenhouses (Panno et al., 2020). During the sampling period, up to 58% of sampled greenhouses and 30% of seed lots were contaminated (Panno et al., 2020). In a greenhouse transmission study, the introduction of two infected tomato plants was enough to damage the entire greenhouse crop, with ToBRFV infection spreading through the greenhouse in an eight month period (Panno et al., 2020).

Tomato and pepper are both important crops in the United States. From 2016–2018, the annual average value of the U.S. tomato crop was $1.85 billion (USDA-NASS, 2020). At the same time, U.S. pepper production was worth an average of $548 million per year (USDA-NASS, 2020). Tomato and pepper are commercially grown in every state, both outdoors and in greenhouses (USDA-NASS, 2020).

ToBRFV is on the European and Mediterranean Plant Protection Organization (EPPO) Alert List (EPPO, 2020). The main purpose of the Alert List is to draw attention to certain pests that possibly present a risk to the region and achieve early warning.

ToBRFV is listed as a harmful organism in the European Union (PExD, 2020). It is also listed as a harmful organism in Argentina, Chile, Costa Rica, New Zealand, South Korea, South Africa, and Taiwan (PExD, 2020). There may be trade implications with any of these areas if this virus becomes established in the United States.

Known Vectors (or associated insects)

Bombus terrestris (buff-tailed bumblebee) is a mechanical vector that is known to transmit ToBRFV through movement of pollen in Europe (Levitzky et al., 2019).

Known Distribution

Africa: Egypt
Asia: China, Israel, Jordan, Palestine
Europe: France, Greece, Italy, Netherlands, Spain, Turkey, United Kingdom
North America: Canada, Mexico

(Alkowni et al., 2019; Amer and Mahmoud, 2020; Cambron-Crisantos et al., 2018; EPPO, 2019a, 2020; Fidan et al., 2019; French Ministry of Agriculture and Food, 2020; Luria et al., 2017; NVWA, 2020; Salem et al., 2016; Skelton et al., 2019; Yan et al., 2019)

ToBRFV was detected and eradicated in Germany (EPPO, 2019b).

Status of infestation in the United States (June 2020)

ToBRFV has been detected in a few greenhouses in the United States (e.g., Ling et al., 2019), but there is insufficient information to determine the status of this virus in the United States.

Pathway

Tobamoviruses are easily spread, and numerous human-mediated pathways are possible (Smith and Dombrovsky, 2019). The detection of this virus across four continents in a short time (EPPO, 2020) is a testament to its ability to spread long distances. ToBRFV is presumably seedborne like other tobamoviruses (Dombrovsky, 2019), and movement of contaminated seed is a likely pathway for long-distance movement. Seed lots from tomato, pepper, and hot pepper have all tested positive for ToBRFV (NVWA, 2020). Infections can sometimes be symptomless (ASTA, 2019), so inadvertent movement of infected planting material may also pose a pathway risk for long distance movement of ToBRFV.

Research has shown that ToBRFV can spread through infected tomato fruit (Klap et al., 2020). Since December 2019, ToBRFV has been intercepted fifteen times on infected tomato fruit from Mexico (AQAS, 2020). Since 2010, *Solanum lycopersicum* plant material has been intercepted 769 times from Mexico at U.S. ports of entry (AQAS, 2020). In addition, *Capsicum annum* plant material from Mexico has been intercepted 2,603 times at U.S. ports of entry since 2010 (AQAS, 2020). These interceptions contained fruit, plant material, or seed (AQAS, 2020).

Use the PPQ Commodity Import and Export manuals listed below to determine 1) if host plants or material are allowed to enter the United States from countries where the organism is present and 2) what phytosanitary measures (e.g., inspections, phytosanitary certificates, post entry quarantines, mandatory treatments) are in use. These manuals are updated regularly.

Fruits and Vegetables Import Requirements (FAVIR) Online Database: The FAVIR database lists all import requirements for fruits and vegetables. To search by commodity, select 'Approved Name' at the top left of the page. Select the commodity from the drop down menu and then click 'Search'. Click on the 'Commodity Summary' tab for details.
https://epermits.aphis.usda.gov/manual/index.cfm?action=pubHome

Plants for Planting Manual: This manual is a resource for regulating imported plants or plant parts for propagation, including buds, bulbs, corms, cuttings, layers, pollen, scions, seeds, tissue, tubers, and like structures.
https://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/plants_for_planting.pdf

Treatment Manual: This manual provides information about treatments applied to imported and domestic commodities to limit the movement of agricultural pests into or within the United States.
https://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/treatment.pdf

Potential Distribution within the United States

Tomatoes and peppers are grown commercially in every U.S. state, either in the field or in greenhouses (USDA-NASS, 2020). They are also popular vegetables for the home gardener (Gunter, 2018). Because the virus may survive in soil, is easily transmitted, and has been found

in greenhouses (Dombrovsky and Smith, 2017; Panno et al., 2019; Ling et al., 2019), ToBRFV could emerge in any part of the United States.

California is the top tomato producing state, and it accounted for about 64% of the total value of the 2018 U.S. tomato crop (USDA-NASS, 2020). Florida, the other major tomato producing state, accounted for about 18% of the value of the 2018 U.S. tomato crop (USDA-NASS, 2020). Other states with significant commercial tomato production include: Georgia, Indiana, Michigan, New Jersey, North Carolina, Ohio, South Carolina, Tennessee, and Virginia (USDA-NASS, 2020).

California is also the leading pepper producing state, and it accounted for more than half of U.S. bell pepper production in 2018 (USDA-NASS, 2020). Florida is another major pepper producing state, and it accounted for about 27% of total U.S. bell pepper production. Other major pepper producing states include: Georgia, Michigan, New Jersey, New Mexico, North Carolina, Ohio, and Texas (USDA-NASS, 2020).

Survey and Key Diagnostics

Approved Methods for Pest Surveillance:

For the current approved methods and guidance for survey and identification, see the Approved Methods for Pest Surveillance (AMPS) pest page on the CAPS Resource and Collaboration website at, https://caps.ceris.purdue.edu/approvedmethods.

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Versions

Version 1, February 2021: Datasheet completed and published as part of the Solanaceous Hosts manual

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