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

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

Scientific Name
Tobamovirus fructirugosum

Synonym(s):
None

Common Name
Tomato brown rugose fruit virus
ToBRFV

Type of Pest
Virus

Taxonomic Position
Class: Alsuviricetes
Order: Martellivirales
Family: Virgaviridae

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).

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
ToBRFV is a single-stranded, positive-sense RNA virus of approximately 6.4 kb. Virions of ToBRFV are rod-shaped and about 300 nm long (Luria et al., 2017) and can only be visualized using an electron microscope.

Damage/Symptoms
Symptoms of ToBRFV infection of tomato leaves include chlorosis, mosaic, mottling, leaf distortion, and possible leaf narrowing (Figs. 1-2) (Cambron-Crisantos et al., 2018; Luria et al., 2017). Infected green parts that attach fruits to the main stem (e.g., calyces, peduncles, 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 necrosis (Davino, 2019a, 2019b) (Fig. 1, 3).

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. (Figure and caption © 2017 Luria et al. is licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/)). The new tobamovirus isolate referred to in the caption is Tomato brown rugose fruit virus.

Infected tomato fruit exhibit yellow and brown discoloration, grooves, deformation, necrosis, and rugosity (wrinkled, roughened surface) (Fig. 1, 2) (Cambron-Crisantos et al., 2018; Fidan et al., 2019; Luria et al., 2017; Panno et al., 2019a; 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. (Figure and caption © 2017 Luria et al. is licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/)).

In tomato plants, symptoms typically develop within 12 to 18 days of infection (Luria, 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 (Luria et al., 2017; Salem et al., 2016).

Easily Mistaken Species

Symptoms caused by ToBRFV cannot be visually distinguished from other plant viruses, and it may be difficult to differentiate ToBRFV symptoms from abiotic symptoms such as nutrient deficiency, herbicide damage, or frost damage. Numerous tobamoviruses are present in the United States and can infect tomato and/or pepper. Some of these viruses include: pepper mild mottle virus (*Tobamovirus capsici*, PMMoV), tobacco mosaic virus (*Tobamovirus tabaci*, TMV), tomato mosaic virus (*Tobamovirus tomatotessellati*, ToMV), tomato mottle mosaic virus (*Tobamovirus maculatessellati*, ToMMV), and tomato spotted wilt virus (TSWV) (Baker et al., 2000). Symptoms presented by these viruses can be similar to those of ToBRFV (Dey, 2019), and molecular identification is necessary to confirm the presence of ToBRFV.

Biology and Ecology

Tobamoviruses are stable and can remain infective in seed, plant residue, farm equipment, and soil for long periods (Davino et al., 2020; Dombrovsky et al., 2017).

Because of their stability, tobamoviruses are mechanically transmitted with ease through contaminated tools, equipment, clothing, workers' hands, crop debris in soil, contaminated propagation materials, irrigation water, and contact between infected plants (Broadbent, 1976; Broadbent et al., 1963; Dey, 2019; Smith et al., 2019). Like other tobamoviruses, ToBRFV is seed-borne, and transmission from infected tomato seeds to plantlets occurs during germination (Davino et al., 2020; Dombrovsky et al., 2017). Infected tomato fruit can serve as an inoculum for spread of ToBRFV to tomato plants (Klap et al., 2020).

Tobamoviruses are known to overwinter in weed hosts, which may serve as inoculum for crop hosts in consecutive growing seasons (Smith et al., 2019). ToBRFV naturally infects several weed species in the Amaranthaceae, Asteraceae, Malvaceae, Oxalidaceae, Portulacaceae, Solanaceae, and Tiliaceae families. These weed species may allow the virus to persist during periods without tomato production (Salem et al., 2022).

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

Transmission of ToBRFV can also occur through movement of pollen by the buff-tailed 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 Pepino mosaic virus between tomato plants (Shipp et al., 2008) and between tomato and nightshade (Stobbs et al., 2014). Additional research is needed to determine whether *B. impatiens* or other pollinators in the United States can spread ToBRFV. Recently, *Phthorimaea absoluta* (=*Tuta*

absoluta, tomato leafminer) was found to transmit ToBRFV primary inoculum under experimental conditions, potentially by direct mechanical transmission as a result of feeding activity (Caruso et al., 2024). Further research is needed to fully understand if *P. absoluta* spreads ToBRFV in greenhouses and fields under natural conditions.

Known Hosts

ToBRFV is known to infect over 40 species belonging to the Amaranthaceae, Apocynaceae, Asteraceae, Malvaceae, Oxalidaceae, Portulacaceae, Scrophulariaceae, Solanaceae, and Tiliaceae families. The most economically important hosts are tomato and pepper but several other hosts are weed species that may serve as a reservoir for ToBRFV (Jewehan et al., 2022; Luria et al., 2017; Salem et al., 2020; Salem et al., 2016; Zhang et al., 2022). Many of the ToBRFV hosts listed below 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

Amaranthus retroflexus (redroot amaranth)*, *Beta vulgaris* subsp. *maritima* (sea beet)*, *Capsicum* spp. (Pepper)*, *Chenopodium murale* (nettleleaf goosefoot)*, *Conyza canadensis* (horseweed)*, *Corchorus olitorius* (jute mallow), *Datura metel* (devil's trumpet)*, *Malva parviflora* (cheeseweed mallow)*, *Oxalis corniculata* (creeping yellow wood-sorrel)*, *Portulaca oleracea* (common purslane)*, *Solanum elaeagnifolium* (silverleaf nightshade)*, *S. nigrum* (black nightshade)*, *Taraxacum officinale* (common dandelion)*, *Veronica syriaca* (Syrian speedwell) (Salem et al., 2022; Zhang, 2022)
*Hosts with known U.S. distribution

A positive test result for ToBRFV in *Solanum melongena* (eggplant) was reported in Mexico in 2018 (EPPO, 2019b) and a latent infection of eggplant was reported following mechanical inoculation in China (Yan et al., 2021). However, eggplant is reported as not a host of ToBRFV in other research studies (Chanda et al., 2021; Fidan et al., 2021; Luria et al., 2017; Panno et al., 2019b).

Pest Importance

Tomato and pepper are both important crops in the United States. In 2022, the annual value of the U.S. tomato crop was $1.81 billion (USDA-NASS, 2024b). The 2022 value of U.S. bell pepper was $697 million (USDA-NASS, 2024b). Tomato and pepper are commercially grown in every state, both outdoors and in greenhouses (USDA-NASS, 2020). In 2022, U.S. tomato production was highest in California and Florida (USDA-NASS, 2024a).

ToBRFV is a global concern for the tomato industry (Hak et al., 2019; Ling et al., 2019b). 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). The Tm-2^2 gene that previously conferred resistance to other tobamoviruses in tomato is not effective against ToBRFV (Fidan et al., 2019; Luria et al., 2017). At this time, tomato cultivars with high resistance to ToBRFV are not commercially available (Zhang et al., 2022), but development of these cultivars is ongoing (Sánchez-Sánchez et al., 2023).

Tobamoviruses are easily transmitted through agricultural systems and are difficult to control (Baker et al., 2000). A survey in Sicily found ToBRFV in seed lots, nurseries, and greenhouses with up to 58% of sampled greenhouses and 30% of seed lots contaminated (Panno et al., 2020). In a greenhouse transmission study, the introduction of two infected tomato plants was enough to damage an entire greenhouse crop, with ToBRFV infection spreading through the greenhouse in an eight month period (Panno et al., 2020).

ToBRFV was added to the European and Mediterranean Plant Protection Organization (EPPO) A2 List in 2020 (EPPO, 2020). The main purpose of the Alert List is to draw attention to certain pests that possibly present a risk to the region. ToBRFV is listed as a harmful organism in the European Union (PExD, 2024) and in Albania, Argentina, Azerbaijan, Brazil, Chile, Costa Rica, Guatemala, Jordan, Mexico, Morocco, New Zealand, South Korea, South Africa, Taiwan, Turkey, and Uzbekistan (PExD, 2024). 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). Recently, *Phthorimaea absoluta* (=*Tuta absoluta,* tomato leafminer) was found to transmit ToBRFV under experimental conditions, potentially by direct mechanical transmission as a result of feeding activity (Caruso et al., 2024). Further research is needed to fully understand if *P. absoluta* spreads ToBRFV in greenhouses and fields under natural conditions.

Known Distribution

ToBRFV is considered widespread in Israel and Syria (EPPO, 2024c).

Countries listed below reported isolated ToBRFV infections, typically in greenhouses, which are currently under eradication or are eradicated but not yet confirmed.
Africa: Morocco (greenhouse)
Asia: China (greenhouse), India (field), Iran (greenhouse), Jordan (greenhouse and field), Lebanon (greenhouse), Saudi Arabia (greenhouse), Uzbekistan (greenhouse)
Europe: Albania (greenhouse), Austria (greenhouse), Belgium (greenhouse), Bulgaria (greenhouse), Czech Republic (greenhouse), Estonia (greenhouse), Finland

(greenhouse), France (greenhouse), Germany (greenhouse), Greece (greenhouse and field), Hungary (greenhouse), Ireland (greenhouse), Italy (greenhouse and nursery), Netherlands (greenhouse), Norway (greenhouse), Poland (greenhouse), Portugal (nursery and field), Slovakia (greenhouse), Slovenia (greenhouse), Spain (greenhouse), Switzerland (greenhouse), Turkey (greenhouse), United Kingdom (greenhouse)
North America: Canada (greenhouse), Mexico (greenhouse and nursery), United States (greenhouse and garden)
Oceania: Australia (greenhouse)
South America: Argentina (greenhouse)

(Abou Kubaa et al., 2022; Alkowni et al., 2019; Amer et al., 2020; Bakhtiyorova et al., 2024; Cambron-Crisantos et al., 2018; Eichmeier et al., 2023; EPPO, 2019a, 2020, 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g, 2021h, 2022, 2023, 2024a, 2024b; Esmaeilzadeh et al., 2022; Fidan et al., 2019; French Ministry of Agriculture, 2020; Guo et al., 2024; Kavya et al., 2024; Ling et al., 2019a; Luria et al., 2017; Mahillon et al., 2022; NVWA, 2020; Obregon et al., 2023; Orfanidou et al., 2022; Sabra et al., 2022; Salem et al., 2016; Salem et al., 2022; Sarkes et al., 2020; Skelton et al., 2019; Skelton et al., 2023; Vučurović et al., 2022; Yan et al., 2019)

Status of infestation in the United States (October 2024)
ToBRFV has been detected in a few greenhouses (e.g., Ling et al., 2019), a community garden (Dey et al., 2021), and in wastewater in Maryland, California, and Louisiana (Brumfield et al., 2022; Rothman et al., 2022; Sherchan et al., 2023). ToBRFV is under official control in the United States (USDA-APHIS, 2024) and infected plants are destroyed.

Pathway

Tobamoviruses are easily spread, and numerous human-mediated pathways are possible (Smith et al., 2019). The detection of ToBRFV across six continents in a short time (EPPO, 2020, 2024c) is a testament to its ability to spread long distances. Like other tobamoviruses, ToBRFV is seed-borne in tomato. The virus is located on the seed coat and sometimes the endosperm, but never the embryo, and transmission from infected seeds to plantlets occurs during germination (Davino et al., 2020; Dombrovsky et al., 2017). The seed transmission rate of ToBRFV was determined to be 2.5% in cotyledons and 1.8% in the third true leaf (Davino et al., 2020). Movement of contaminated seed is a likely pathway for long-distance movement of ToBRFV. 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). However, USDA APHIS updated and issued a Federal Order in 2024 which deregulates ToBRFV-positive tomatoes and peppers for consumption. This Federal Order is based on analyses concluding that ToBRFV is unlikely to reach commercial production areas in the U.S. through fruit brought to market for consumption (USDA-

APHIS, 2024). ToBRFV has been intercepted at the US border in fruit, plant material, and seeds (AQAS, 2019).

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.

Agricultural Commodity Import Requirements (ACIR) manual: ACIR provides a single source to search for and retrieve entry requirements for imported commodities. https://acir.aphis.usda.gov/s/

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://acir.aphis.usda.gov/s/treatment-hub

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 et al., 2017; Panno et al., 2019a; Ling et al., 2019), ToBRFV can emerge in any part of the United States.

California and Florida are the top two tomato producing states, accounting for about 67% and 16%, respectively, of the total value of the 2022 U.S. tomato crop (including greenhouse and field-grown tomatoes) (USDA-NASS, 2024a). Other states with significant field tomato production include Indiana, Michigan, Ohio, Tennessee, New Jersey, Pennsylvania, South Carolina, North Carolina, Virginia, and New York. States with significant greenhouse tomato production include Ohio, New York, Texas, Kentucky, Michigan, Iowa, Illinois, Pennsylvania, Missouri, and Virginia (USDA-NASS, 2024a).

California and Florida accounted for about 38% and 40% of the value of U.S. bell pepper production in 2022, respectively. Other major pepper producing states include Georgia, New Jersey, Michigan, and North Carolina (USDA-NASS, 2024b).

Survey and Key Diagnostics

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://approvedmethods.ceris.purdue.edu/

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Versions

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