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

'*Candidatus* Phytoplasma phoenicium'

Scientific Name
'Candidatus Phytoplasma phoenicium' Verdin et al., 2003

Synonym:
Phytoplasma phoenicium

Common Names
Almond witches' broom phytoplasma

Type of Pest
Phytoplasma

Taxonomic Position
Class: Mollicutes
Order: Acholeplasmatales
Family: Acholeplasmataceae

Figure 1: Witches' broom symptoms in almond infected with '*Ca*. P. phoenicium'. Courtesy of Yusuf Abou-Jawdah and Marina Molino-Lova.

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 AMPS pest page on the CAPS Resource and Collaboration website.

Pest Description

Phytoplasmas are cell wall-less, unculturable bacteria that colonize the phloem of host plants and are typically vectored by phloem-feeding insects (Bertaccini et al., 2022; Verdin et al., 2003). The genus '*Candidatus* Phytoplasma' is associated with over one thousand plant diseases worldwide (Bertaccini et al., 2022). Species within this genus are classified primarily based on phylogenetic analysis of the 16S ribosomal RNA gene sequences and, increasingly, on whole genome sequences (Bertaccini et al., 2022).

The species *'Candidatus* Phytoplasma phoenicium' is a member of the pigeon pea witches'-broom (PPWB) phytoplasma group 16SrIX (Verdin et al., 2003). Several different strains of '*Ca.* P. phoenicium' have been identified, belonging to various subgroups: 16SrIX-B, -C -D, -F, and -G (Molino Lova et al., 2011a). The original reference strain A4 associated with the new species description by Verdin et al. is a

member of 16SrIX-D (2003). Strains from subgroups 16SrIX-B,-C, -D and -G are associated with almond witches'-broom (AlmWB) disease in Lebanon, Iran, and Italy (Nigro et al., 2020; Salehi et al., 2006; Verdin et al., 2003). Almond witches'-broom (AlmWB) is a devastating disease that affects not only almond, but also peach, nectarine, and apricot (Abou-Jawdah et al., 2002; Molino Lova et al., 2011b; Salehi et al., 2018).

Symptoms

In almond**:** Symptoms include early flowering, stunted growth, leaf rosetting (short, bunchy growth habit due to shortened internodes and reduction in leaf size), dieback, off-season growth, proliferation of slender shoots, witches'-broom, and smaller pale green leaves (Fig. 1, 2, 3) (Abou-Jawdah et al., 2002; personal communication Abou-Jawdah, 2016). Witches'-broom symptoms arise mainly from the trunk or roots but can also occur on branches (Fig. 1). Fruits produced from infected trees are smaller and darker in color with shriveled seeds, and fruit yield on infected branches is greatly reduced (Abou-Jawdah et al., 2002).

This phytoplasma disease can be asymptomatic in almond hosts (Abou-Jawdah et al.,

Figure 2: Shoot proliferation (left) and witches'-broom, dieback (right) from '*Ca*. P. phoenicium' infection in almond. Courtesy of Yusuf Abou-Jawdah and Marina Molino-Lova.

2002) and some almond cultivars are more susceptible to '*Ca.* P. phoenicium' than others (Verdin et al., 2003). The susceptibility of almond cultivars grown in the United States is not currently known.

Figure 3: An infected almond branch (left) vs. a healthy branch (right) in both images. Courtesy of Yusuf Abou-Jawdah and Marina Molino-Lova.

In peach/nectarine: Symptoms early in the growing season include premature flowering followed by the early development of buds (Molino Lova et al., 2011b) (Fig. 4). Symptoms later in the growing season include shoot proliferation, smaller leaves with a pale green color (Fig. 3, 5), abnormal flowers (phyllody), and, in rare cases, witches'-broom (Abou-Jawdah et al., 2010). Most infected trees do not set any fruit, but some trees bear a limited number of deformed fruits (Abou-Jawdah et al., 2010).

Figure 5. Left: A healthy peach tree and an infected peach tree (red arrow). Right: Shoot proliferation in an infected nectarine. Courtesy of Yusuf Abou-Jawdah and Marina Molino-Lova.

In apricot: Symptoms include leaf yellowing, shortened internodes, inward leaf curl, scorched leaf margins, leaf rosetting, die back, and plant death. Symptoms typically first emerge on one branch or a section of branches before spreading, and affected

branches produce no fruit or fruit abnormal in size, shape, and taste (Salehi et al., 2018).

Easily Mistaken Species

'*Candidatus* Phytoplasma phoenicium' infection may be confused with infection of other phytoplasmas such as '*Ca.* P. prunorum', '*Ca*. P. pruni', and '*Ca.* P. aurantifolia', which also infect stone fruit (Davis et al., 2013; Salehi et al., 2020; Seemüller and Schneider, 2004). Of the three, only '*Ca*. P. pruni' is present in the United States. Visible symptoms alone are insufficient to diagnose phytoplasma infection, and molecular confirmation is critical for accurate identification.

Biology and Ecology

Phytoplasmas live exclusively in the phloem of plants and in the body of insect vectors. They are mainly transmitted among plants by phloem-feeding insects and by vegetative propagation (grafting, cuttings, bulbs, etc.) of infected plant tissues (Lee et al., 2000). Some phytoplasmas persist throughout the year in weed species acting as reservoir hosts for the pathogen (Mall et al., 2010).

During an inoculation study by Abou-Jawdah et al. (2014), '*Ca*. P. phoenicium' was detected in infected almond and peach seedlings that did not show characteristic witches'-broom symptoms for one year post-inoculation. The study suggests the disease incubation period may be longer than one year.

Early flowering (20 to 30 days earlier than normal) was the first symptom of '*Ca.* P. phoenicium' infection observed in a survey of almond trees in Lebanon, followed by the growth of witches'-brooms on the main trunk (Abou-Jawdah et al., 2002). One year later, symptoms such as shoot proliferation, shoot stunting, formation of unusually small leaves, rosetting, and reduced fruit yield were observed. The infected trees declined rapidly and died within three to four years of symptom onset (Abou-Jawdah et al., 2002).

The rapid spread of '*Ca*. P. phoenicium' over large geographic areas in North Lebanon suggested the presence of an efficient vector (Abou-Jawdah et al., 2010), and at least three insect vectors in Lebanon have been identified (Abou-Jawdah et al., 2014; Tedeschi et al., 2015). The planthoppers *Tachycixius cypricus* and *Tachycixius viperinus* are known to transmit the phytoplasma to peach (Tedeschi et al., 2015), and the leafhopper *Asymmetrasca decedens* transmits the phytoplasma to both almond and peach (Abou-Jawdah et al., 2014).

Several other insects have also been identified as carriers of '*Ca.* P. phoenicium' in Lebanon but are currently not confirmed to be vectors (see Known Vectors). *Smilax aspera* (rough bindweed) and *Anthemis* spp. (chamomile), are weed hosts of '*Ca*. P. phoenicium' in Lebanon that likely act as reservoirs for the phytoplasma, contributing to the spread of AlmWB disease to stone fruit hosts (Tedeschi et al., 2015). *Tachycixius cypricus* and *Tachycixius viperinus* were collected from these weed hosts and were found to be infected with '*Ca*. P. phoenicium' (Tedeschi et al., 2015).

Known Hosts

'*Ca.* P. phoenicium' infects several species in the *Prunus* genus including almond, peach, nectarine, and apricot.

'*Ca.* P. phoenicium' also infects several non-*Prunus* hosts. Weeds have been described as reservoirs of important phytoplasmas (Mall et al., 2010), and the species listed below in "Other hosts" may serve as natural reservoirs of '*Ca*. P. phoenicium'.

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 feeding and damage documented in the literature. Plants are highlighted in bold if they are commercially produced and the pest causes economically significant damage.

Table 1. Preferred hosts of '*Ca.* P. phoenicium'.

Scientific Name	Common Name	Presence in the US	Type/Use	Reference
Prunus dulcis	almond	Present	Cultivated	Verdin et al., 2003
Prunus dulcis* x *Prunus persica	GF-677 almond/peach hybrid	Present	Cultivated	Salehi et al., 2011
Prunus persica	peach	Present	Cultivated	Abou-Jawdah et al., 2010
Prunus persica* var. *nucipersica	nectarine	Present	Cultivated	Salehi et al., 2006
Prunus armeniaca	apricot	Present	Cultivated	Salehi et al., 2018

Other hosts

Anthemis spp. (chamomile)*, *Catharanthus roseus* (Madagascar periwinkle)*; *Citrus sinensis* (sweet orange)*, *Lactuca sativa* (lettuce)*, *Lactuca serricola* (wild lettuce)*, *Prunus domestica* subsp. *italica* (greengage)*, *Prunus scoparia* (wild almond), and *Smilax aspera* (rough bindweed) (Abbasi et al., 2019; Salehi et al., 2007; Salehi et al., 2015; Salehi et al., 2022; Tedeschi et al., 2015; Verdin et al., 2003).

* Host with known U.S. distribution.

Pest Importance

AlmWB disease has killed over 150,000 almond trees in Lebanon (Abou-Jawdah et al., 2014), and surveys have identified thousands of infected peach and nectarine trees (Molino Lova et al., 2011b). Dieback from AlmWB may affect all trees in an orchard planted with highly susceptible almond cultivars (Verdin et al., 2003). Total loss of commercial yield in infected almond or peach trees can occur one year after the initial observation of symptoms (Abou-Jawdah, 2016).

Almonds are an important specialty crop in the United States and are California's highest valued export commodity (CDFA, 2020). In 2022, almonds were grown on 1.35 million bearing acres in the state (NASS, 2022). The 2022 almond harvest in CA was 2.53 billion pounds and a total estimated value of $3.54 billion (NASS, 2022).

Peaches, nectarines, and apricots are also important specialty crops in the United States. In 2022, peaches, nectarines, and apricots were grown on over 98,600 bearing acres in the United States, and the total combined production value of these crops was over $872 million (NASS, 2022).

'*Candidatus* Phytoplasma phoenicium' was first added to the European and Mediterranean Plant Protection Organization (EPPO) Alert List in 2001 and removed from the list in 2006. Since then, due to rapid spread of AlmWB in Lebanon and the discovery of peach and nectarine as additional hosts, '*Ca.* P. phoenicium' was again added to the EPPO Alert List in 2015 and in 2017 (EPPO, 2024). Morocco listed *'Ca.* P. phoenicium as a quarantine pest in 2018, and the United Kingdom and Switzerland added it to the A1 List in 2020 and 2022, respectively (EPPO, 2024).

Known Vectors (or associated insects)

There are three confirmed vectors of '*Ca*. P. phoenicium':

- *Asymmetrasca decedens* (syn. *Empoasca decedens*) (Fig. 6 shows an *Empoasca* sp. very similar in appearance to *A. decedens*) (Abou-Jawdah et al., 2014)
- *Tachycixius* cf *cypricus* (Tedeschi et al., 2015)
- *Tachycixius viperinus* (Tedeschi et al., 2015)

To date, these vectors have not been reported to occur in the United States.

Figure 6: *Empoasca* sp., a leafhopper very similar in appearance to the vector *Asymmetrasca decedens* (syn. *Empoasca decedens*). Cybernadette, Wikimedia commons, CC-BY-SA-3.0

Other known insect carriers of '*Ca*. P. phoenicium' that are not confirmed vectors are: *Allygus* sp., *Annoplotettix danutae*, *Balclutha* sp., *Cixius bifidispinus, Cixius* sp., *Empoasca decipiens*, *Eumecurus* sp., *Euscelidius mundus*, *Fieberiella macchiae*, *Lylatina inexpectata*, *Tachycixius bidentifer*, *Tachycixius* cf *creticus,* and *Thamnottetix seclusis* (Dakhil et al., 2011; Picciau et al., 2016; Tedeschi et al., 2015).

Merely detecting phytoplasma in an insect is not proof that the insect transmits the phytoplasma (Dakhil et al., 2011). Transmission studies must be conducted to confirm the species listed above can vector *'Ca*. P. phoenicium'.

Known Distribution

Table 2. Countries where '*Ca*. P. phoenicium' is known to occur.

Region/Continent	Country	Reference
Asia	Lebanon	Verdin et al., 2003
Asia	Iran	Salehi et al., 2006
Europe	Italy	Nigro et al., 2020

Pathway

Long distance transport of phytoplasmas is most likely to occur via movement of infected host plant material and via movement of infected insect vectors. The incubation period of '*Ca.* P. phoenicium' in plants may be more than one year before visual symptoms become apparent (Abou-Jawdah et al., 2014).

Currently, *Prunus* spp. originating from any country other than from Canada and the Netherlands are Not Authorized Pending Pest Risk Analysis (NAPPRA) (USDA, 2024). Small quantities of *Prunus* spp. may be imported under a controlled import permit (CIP) for experimental, therapeutic, or developmental purposes (USDA, 2024).

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://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/treatment.pdf

Potential Distribution within the United States

In the United States, California is the most vulnerable to infection by '*Ca*. P. phoenicium' due to its significant almond cultivation (NASS, 2022). In addition, California is the top peach producing state and accounts for about two thirds of the nation's peach production (NASS, 2022). The other top peach producing states in 2022 were, in order: South Carolina, Georgia, Pennsylvania, Colorado, Michigan, New Jersey, and Washington (NASS, 2022). In addition, *Anthemis* (chamomile) spp. are widespread throughout the United States, including throughout California (Kartesz, 2015). Other hosts of '*Ca* P. phoenicium' present in California include *Catharanthus roseus* (Madagascar periwinkle), *Citrus sinensis* (sweet orange), *Lactuca sativa* (lettuce), *Lactuca serriola* (wild lettuce), and *Prunus domestica* subsp. *italica* (greengage) (Kartesz, 2015).

The leafhopper insect vector *Asymmetrasca decedens* is present throughout the Mediterranean region in Europe (Freitas and Aguin-Pombo, 2006), so it may also be able to survive in California, which has a similar climate. *A. decedens* is not currently present in the U.S.

Survey and Key Diagnostics

Approved Methods for Pest Surveillance:

For the current approved methods and guidance for survey and identification, see 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

June 2016: Datasheet posted to CAPS Resource and Collaboration site (Version 1)
April 2024: (Version 2)

- Removed **Background Information** section
- Revised **Pest Recognition** section and added symptoms on apricot
- Added '*Ca.* P. aurantifolia' to **Easily Mistaken Species** section
- Revised **Known Hosts** section and added apricot, sweet orange and greengage as hosts. Updated reference for lettuce and wild lettuce hosts
- Revised **Pest Importance** section with updated statistics and EPPO Alert List information
- Added Italy to **Known Distribution** section
- Revised **Pathway** section
- **Revised Potential Distribution** with the United States section with updated statistics
- Removed outdated "Combined Host Density" map
- Revised **In Progress/Literature-Based Methods** section
- Revised **Survey and Key Diagnostics** section

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