Chapter 11
Phytoplasmas in Weeds and Wild Plants

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Abstract Weeds and wild plants as hosts of phytoplasmas play an important role in the epidemiology and emergence of phytoplasma diseases of economically important crops. In this chapter phytoplasmas detected in weeds and wild plants, their geographic origins, symptoms, identification, and their role in natural dissemination of phytoplasmas are described.

Keywords Reservoir · Overwintering · Epidemiology · Source of inoculum · Plant diseases

11.1 Introduction

To date, phytoplasmas have been associated with diseases in several hundred plant species in which they induce symptoms such as virescence, phyllody, sterility of flowers, witches' broom growth, elongation of internodes, overall stunting, discoloration of leaves/shoots, leaf curling, and plant decline. Phytoplasmas are transmitted from plant to plant mainly by sap-sucking insects, and they may overwinter in perennial plants which can act as their reservoirs for spreading in the following spring. In many important crops all over the world, phytoplasmas induce diseases that sometimes lead to severe economic losses in agronomically relevant species such as carrot, corn, potato, rice, grapevine, and palms. Therefore, throughout the world, different weeds and wild plants, with and without symptoms, have been tested to identify possible reservoir plants for phytoplasmas (Schneider et al. 1997;

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Mall et al. 2010; Win et al. 2013; Rao et al. 2017b). At the beginning of phytoplasma research, phytoplasmas were detected by characteristic symptoms and by observation of round or filamentous bodies in sieve tubes of diseased plants by transmission electron microscopy (TEM). Over the years, as molecular techniques evolved, introduction of PCR assays for detection and identification enabled further studies of the ecology and genomic diversity of phytoplasmas as well as the epidemiology and physiology of phytoplasma-associated diseases (Seemüller et al. 1994; Lee et al. 2000).

Some weeds or wild plants in which phytoplasma presence was recorded by observation only and therefore without proper identification are listed thereafter. In Korea, phytoplasma bodies were observed in the phloem tissues of *Cnidium officinale*, *Bupleurum falcatum*, and *Plantago asiatica* by electron microscopy (Choi et al. 1985). In Jamaica, Dabek (1983) used electron microscopy to confirm the presence of phytoplasmas in *Rhynchosia minima* with a disease called *Rhynchosia* little leaf (RLL) and managed to transmit the disease agent to *R. minima* test plants by the insect vector *Ollarianus balli* (van Duzee 1907). In India, the association of phytoplasma bodies with white leaf disease was observed in Bermuda grass – *Cynodon dactylon* (Singh et al. 1978). The symptoms associated with phytoplasma presence, which lead to the rice yellow dwarf disease, were observed in the common grass weed, *Echinochloa colonum* (Reddy and Jeyarajan 1988). Pleomorphic phytoplasma bodies were observed in symptomatic *C. dactylon* plants and yellowing diseased *Urochloa panicoides* in South India (Muniyappa et al. 1982). Rao and Singh (1990) observed grassy shoot and white leaf symptoms on *Imperata arundinacea* (Poaceae) growing in the vicinity of sugarcane fields and reported that the symptoms were associated with phytoplasma. *I. arundinacea* was then reported as a new alternative host species of the phytoplasma associated with sugarcane grassy shoot disease. In India, in *Phyllanthus amarus* with overall retarded growth symptoms, phytoplasma presence was confirmed by TEM (Samad et al. 2004).

Besides these reports, phytoplasmas identified in weeds all over the globe mainly belong to the 16SrI, 16SrII, 16SrXI, 16SrXII, and 16SrXIV groups, but some members belonging to the 16SrIII, 16SrIV, 16SrV, 16SrVI, 16SrVII, 16SrIX, 16SrX, and 16SrXXIX groups were also detected. A list of phytoplasmas detected in weeds and wild plants and their geographic origins is provided in Table 11.1.

11.2 Phytoplasmas in 16SrI Group (Aster Yellows)

In Italy, pot marigold (*Calendula officinalis*) collected inside apricot and plum orchards near vegetable crops affected by aster yellows (AY) were infected with phytoplasmas belonging to the 16SrI-B subgroup (Marcone et al. 1997b). AY phytoplasma was detected in *Portulaca oleracea* (purslane) collected from apricot orchards in Italy, in *Cardaria draba* (hoary cress) and *Bunias orientalis* (hill mustard) collected from an agricultural area, and in *Stellaria media* (common chickweed) and *Trifolium repens* (white clover) collected in or around apple/stone fruit orchards in Germany (Schneider et al. 1997). In the United Kingdom, AY

Table 11.1 Summary of phytoplasmas reported in weeds and wild plant species

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Acalypha indica	Indian nettle	16SrI	India	Tiwari et al. (2017)
Achyranthes aspera	Devil's horsewhip	16SrI	India	Raj et al. (2009a)
		16SrII	Oman	Moghal et al. (1998)
Aegilops squarrosa	Goat grass	16SrI	China	Wu et al. (2010)
Aeschynomene americana	American jointvetch	16SrII	Australia	Wilson et al. (2001)
Aeschynomene indica	Indian jointvetch	16SrII	Australia	Schneider et al. (1999)
Ageratum conyzoides	Goat weed	16SrI	India	Tiwari et al. (2012)
Alysicarpus rugosus	Rough chainweed	16SrII	Australia	Davis et al. (1997)
Alysicarpus vaginalis	Alyce clover	16SrII	Australia	Wilson et al. (2001)
Amaranthus retroflexus	Redroot pigweed	16SrI	China	Wu et al. (2010)
		16SrV-B		Yang et al. (2011)
		16SrXII-A	Italy	Credi et al. (2006)
			Czech Republic	Fialová et al. (2009)
Amaranthus sp.		16SrII	India	Arocha et al. (2008)
Aphyllodium sp.		16SrII	Australia	Schneider et al. (1999)
Arachis pintoi	Pinto's peanut	16SrII	Australia	Schneider et al. (1999)
Artemisia vulgaris	Common wormwood	16SrXII-A	Italy	Credi et al. (2006)
Arundo donax	Giant reed	16SrXIV	Saudi Arabia	Omar (2016)
Avena fatua	Wild oat	16SrI	China	Wu et al. (2010)
Axonopus compressus	Broadleaf carpet grass	16SrXIV	Thailand	Sunpapao (2016)
			Singapore	Koh et al. (2008)
Bidens alba	Shepherd's needles	16SrIX	Iran	Hemmati et al. (2017)
Bonamia pannosa		16SrII	Australia	Schneider et al. (1999)
Brachiaria brizantha	Signal grass	16SrXI	Africa	Asudi et al. (2016)
		16SrXIV		
Brachiaria distachya	Brachiaria grass	16SrXIV	Thailand	Seemüller et al. (1998)
Brugmansia candida	Angel's trumpet	16SrII	Australia	Davis et al. (1997)
Bunias orientalis	Hill mustard	16SrI	Germany	Schneider et al. (1997)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Bupleurum falcatum	Chinese thorowax	UDG	Korea	Choi et al. (1985)
Cajanus marmoratus		16SrII	Australia	Schneider et al. (1999)
Calendula arvensis	Field marigold	16SrII-E	Italy	Tolu et al. (2006)
Calendula officinalis	Pot marigold	16SrI	Italy	Marcone et al. (1997b)
		16SrII	Iran	Esmailzadeh Hosseini et al. (2011a)
Calotropis gigantea	Crown flower	16SrVI	India	Madupriya et al. (2010)
Calystegia sepium	Hedge bindweed	16SrXII-A	Italy	Credi et al. (2006)
Cannabis sativa	Hemp	16SrI	India	Mall et al. (2015)
				Raj et al. (2008b)
				Nabi et al. (2015a)
Cardaria draba	Hoary cress	16SrI	Germany	Schneider et al. 1997
		16SrII	Iran	Esmailzadeh Hosseini et al. (2011b)
Cassia italica	Italian senna	16SrXXIX-A	Oman	Al-Saady et al. (2008)
Cenchrus ciliaris	Buffel grass	16SrII	Australia	Tran-Nguyen et al. (2000)
Cenchrus setiger	Birdwood grass	UDG	Australia	Tran-Nguyen et al. (2000)
Centrosema pascuorum	Cavalcade	16SrII	Australia	Wilson et al. (2001)
Chenopodium album	Lamb's quarter	16SrXII-A	Italy	Credi et al. (2006)
Chenopodium ambrosioides	Epazote	16SrI	China	Li et al. (2012)
Chenopodium murale	Nettle-leaved goosefoot	16SrII	Saudi Arabia	Alhudaib et al. (2009)
Chenopodium sp.		16SrII	Italy	Tolu et al. (2006)
Chloris gayana	Rhodes grass	16SrXI	East Africa	Asudi et al. (2016)
Chloris inflata	Purpletop Rhodes grass	16SrXI	Australia	Blanche et al. (2003)
Chrysopogon aciculatus	Golden beard grass	16SrXIV	Myanmar	Win and Jung (2012)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Cirsium arvense	Canada thistle	16SrXI-E	Germany	Schneider et al. (1997)
			Czech Republic	Šafářová et al. (2016)
		16SrXII-A	Italy	Credi et al. (2006)
			Czech Republic	Fialová et al. (2009)
		16SrIII	Serbia	Rančić et al. (2005)
Cirsium sp.		16SrIII	Hungary	Palermo et al. (2004)
Cleome viscosa	Tick weed	16SrII	Australia	Schneider et al. (1999)
			India	Thorat et al. (2016)
Cnidium officinale		UDG	Korea	Choi et al. (1985)
Coix lacryma-jobi	"Otiro"	16SrXI	East Africa	Asudi et al. (2016)
Convolvulus arvensis	Field bindweed	16SrII	Saudi Arabia	Alhudaib et al. (2009)
		16SrIII	Hungary	Palermo et al. (2004)
		16SrX	Germany	Schneider et al. (1997)
		16SrXII-A	Europe, Iran, Israel	Batlle et al. (2000), Berger et al. (2009)
		16SrXII-H	Italy, Serbia, Bosnia and Herzegovina, Germany	Martini et al. (2012)
			Austria	Aryan et al. (2014)
		16SrXXIX-B	Iran	Esmailzadeh Hosseini et al. (2016a)
Conyza canadensis	Canadian horseweed	16SrIII	USA	Schneider et al. (1997)
		16SrVI	Iran	Zibadoost and Rastgou (2016)
Crepis setosa	Hawksbeard	16SrXI	Italy	Marcone et al. (1997b), Schneider et al. (1997)
Crotalaria brevis		16SrII	Australia	Schneider et al. (1999)
Crotalaria crispata		16SrII	Australia	Schneider et al. (1999)
Crotalaria goreensis	Blunt bird flower/ Gambia pea	16SrII	Australia	Davis et al. (1997), Wilson et al. (2001)
Crotalaria novae-hollandiae	New Holland rattlepod	16SrII	Australia	Davis et al. (1997)
Crotalaria pallida	Smooth rattlepods	16SrII	India	Yadav et al. (2016)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Crotalaria sp.		16SrII	Australia	Davis et al. (1997)
Crotalaria spectabilis	Showy rattlebox	16SrI	India	Kumar et al. (2010)
		16SrII	Australia	Schneider et al. (1999)
Crotalaria tetragona		16SrI	India	Baiswar et al. (2010)
Cyanthillium cinereum	Little ironweed	16SrII	Australia	Schneider et al. (1999)
Cynodon dactylon	Bermuda grass/ couch	16SrII	Australia	Tran-Nguyen et al. (2000)
		16SrXI	East Africa	Asudi et al. (2016)
		16SrXIV	Europe, Asia, Africa, Cuba	Chen et al. (1972)
				Mitrović et al. (2015)
				Khanna et al. (2015)
Cyperus rotundus	Coco grass	16SrII	Cuba	Zamora et al. (2015)
Dactyloctenium aegyptium	Crowfoot grass	16SrXI	Australia	Blanche et al. (2003)
		16SrXIV		
Dactyloctenium radulans	Button grass	16SrXI	Australia	Blanche et al. (2003)
Dahlia sp.		16SrXI-E	Czech Republic	Šafářová et al. (2016)
Datura inoxia	Downy thorn-apple	16SrVI	India	Raj et al. (2009b)
Datura stramonium	Jimsonweed	16SrVI	India	Singh et al. (2012)
				Mall et al. (2015)
		16SrXII-A	Italy	Credi et al. (2006)
			Czech Republic	Fialová et al. (2009)
Delphinium sp.		16SrIII	England	Harju et al. (2008)
Descurainia sophia	Flixweed-tansy mustard	16SrI	China	Wu et al. (2010)
Desmodium intortum	Greenleaf tick trefoil	16SrII	Australia	Schneider et al. (1999)
Dichanthium annulatum	Marvel grass	16SrXIV	India	Rao et al. (2009)
				Mall et al. (2015)
Digitaria ciliaris	Southern crabgrass	16SrXIV	India	Mall et al. (2015)
Digitaria sanguinalis	Hairy crabgrass	16SrXIV	India	Rao et al. (2010)
				Mall et al. (2015)
Digitaria scalarum	Couch grass	16SrXI	East Africa	Asudi et al. (2016)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Diplacrum capitatum		16SrXXII-B	Côte D'Ivoire	Arocha Rosete et al. (2016)
Dodonaea angustifolia	Sand olive shrub	16SrXIV	Saudi Arabia	Omar (2016)
Echinochloa colonum	Jungle rice		India	Reddy and Jeyarajan (1988)
Echium vulgare	Blueweed	16SrXI	Italy	Marcone et al. (1997b)
		16SrXII-A		Berger et al. (2009)
Eleusine indica	Goosegrass	16SrXI	Myanmar	Win et al. (2013)
			Africa	Asudi et al. (2016)
		16SrXIV	India	Mall et al. (2015)
			Africa	Asudi et al. (2016)
Emilia fosbergii	Florida tasselflower	16SrIV	Jamaica	Brown et al. (2008a)
Emilia sonchifolia	Lilac tasselflower	16SrII-D	Australia	Schneider et al. (1999)
Enteropogon macrostachyus	Bush rye	16SrXI	East Africa	Asudi et al. (2016)
Eragrostis cilianensis	Stink grass	16SrI	China	Wu et al. (2010)
Eragrostis falcata	Sickle lovegrass	16SrII	Australia	Tran-Nguyen et al. (2000)
Eriachne obtusa		16SrII	Australia	Tran-Nguyen et al. (2000)
Erigeron sp.		16SrVII-B	Brazil	Barros et al. (2002)
Erigeron bonariensis	Flax-leaved fleabane	16SrVII-B	Brazil	Montano et al. (2014)
		16SrVII-D	Brazil	Flôres et al. (2015)
Erysimum cheiranthoides	Wormseed mustard	16SrI	China	Wu et al. (2010)
Euphorbia milii	Crown of thorns	16SrII-D	Australia	Davis et al. (1997)
Festuca arundinacea	Tall fescue	16SrI	Lithuania	Valiūnas et al. (2007)
Galactia tenuiflora		UDG	Australia	Schneider et al. (1999)
Gerbera sp.		16SrII-D	Australia	Davis et al. (1997)
Goodenia sp.		16SrII-D	Australia	Schneider et al. (1999)
Guizotia abyssinica	Niga	16SrII-D	Australia	Davis et al. (1997)
Hyparrhenia cymbaria	Boat thatching grass	16SrXI	East Africa	Asudi et al. (2016)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Hyparrhenia rufa	Giant thatching grass	16SrXI	Africa	Obura et al. (2011)
				Asudi et al. (2016)
		16SrXIV		
Indigofera colutea	Rusty indigo	16SrII	Australia	Schneider et al. (1999)
Ipomoea plebeia	Bell vine	16SrII-D	Australia	Davis et al. (1997)
Knautia arvensis	Field scabious	16SrXI	Italy	Marcone et al. (1997b)
Lavandula officinalis	Lavender	16SrXII-A	Spain	Batlle et al. (2000)
Lavandula angustifolia	Lavender	16SrXII-A	France	Gaudin et al. (2011)
Lithospermum arvense	Corn gromwell	16SrI	China	Wu et al. (2010)
Macroptilium atropurpureum	Purple bean	16SrII-D	Australia	Davis et al. (1997)
Macroptilium bracteatum	Burgundy bean	16SrII	Australia	Schneider et al. (1999)
Macroptilium gracile		16SrII	Australia	Schneider et al. (1999)
Macroptilium lathyroides	Phasey bean	16SrII-D	Australia	Davis et al. (1997)
Malva sylvestris	Common mallow	16SrXII-A	Italy	Credi et al. (2006)
Medicago sativa	Lucerne, alfalfa	16SrII	Australia	Wilson et al. (2001)
		16SrXII-A	Italy	Credi et al. (2006)
			Iran	Esmailzadeh Hosseini et al. (2016c)
		16SrII-D	Oman	Khan et al. (2002)
		16SrII-C/D	Iran	Esmailzadeh Hosseini et al. (2016b)
		16SrVI-A	Iran	Esmailzadeh Hosseini et al. (2016c)
Melochia corchorifolia	Chocolateweed	16SrI	China	Chen et al. (2017)
Mentha arvensis	Wild mint	16SrXII-A	Italy	Credi et al. (2006)
Mikania sp.		16SrI	Bangladesh	Kelly et al. (2009)
Mimosa pudica	Sensitive plant	16SrI	Indonesia	Boa et al. (2010)
Mitracarpus hirtus	Tropical girdlepod	16SrII	Australia	Wilson et al. (2001)
Oplismenus burmannii	Burmann's basketgrass	16SrII	India	Mall et al. (2015)
		16SrXIV	India	Rao et al. (2010)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Parthenium hysterophorus	Santa Maria feverfew	16SrI	India	Raj et al. (2008a)
		16SrII	Ethiopia	Bekele et al. (2011)
			India	Mall et al. (2015)
				Thorat et al. (2016)
			China	Cai et al. (2016)
				Li et al. (2011)
Paspalum conjugatum	Buffalo grass	16SrXIV	Singapore	Koh et al. (2008)
Paspalum vaginatum	Seashore paspalum/biscuit grass	16SrXXII-B	Côte D'Ivoire	Arocha Rosete et al. (2016)
Pennisetum pedicillatum	Desho grass	16SrXXII-B	Côte D'Ivoire	Arocha Rosete et al. (2016)
Phalaris minor	Little seed canary grass	16SrI	India	Mall et al. (2015)
Phlox sp.	Perennial phlox	16SrII-D	Australia	Davis et al. (1997)
Phragmites australis	Common reed	16SrV	China	Li et al. (2013)
Phyllanthus amarus	Shatterstone		India	Samad et al. (2004)
Phyllanthus maderaspanatus		16SrII	Australia	Schneider et al. (1999)
Phyllanthus niruri	Gale of the wind	16SrI	India	Chaube et al. (2015)
Physalis minima	Wild gooseberry	16SrII-D	Australia	Davis et al. (1997)
Phyllanthus muellerianus		16SrXXII-B	Côte D'Ivoire	Arocha Rosete et al. (2016)
Picris echioides	Bristly oxtongue	16SrII-E	Italy	Marcone et al. (1997b)
		16SrIX-C	Italy	Schneider et al. (1997)
		16SrXII-A	Italy	Credi et al. (2006)
Plantago asiatica	Chinese plantain		Korea	Choi et al. (1985)
Plantago lanceolata	Narrowleaf plantain	16SrII	Saudi Arabia	Alhudaib et al. (2009)
		16SrXII-A	Italy	Credi et al. (2006)
			Spain	Batlle et al. 2000
Poa annua	Annual blue grass	16SrXIV-C	Italy	Lee et al. (1997)
Poa pratensis	Common meadow grass	16SrI	Lithuania	Valiūnas et al. (2007)
Polygala mascatense		16SrII	Oman	Livingston et al. (2006)
Polygonum aviculare	Common knotgrass	16SrXII-A	Italy	Berger et al. (2009)

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Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Polygonum convolvulus	Wild buckwheat	16SrXII-A	Spain	Batlle et al. (2000)
Portulaca grandiflora	Moss rose	16SrXIV	India	Ajaykumar et al. (2007)
Portulaca oleracea	Purslane	16SrI	Italy	Schneider et al. (1997)
Potentilla reptans	Creeping cinquefoil	16SrXII-A	Italy	Credi et al. (2006)
Prosopis farcta	Syrian mesquite	16SrII	Iran	Esmailzadeh Hosseini et al. (2011b)
Pterocaulon sp.		16SrII	Australia	Wilson et al. (2001)
Ptilotus distans		16SrII-D	Australia	Schneider et al. (1999)
Ranunculus sceleratus	Cursed buttercup	16SrXIV	India	Singh et al. (2013)
Rhynchosia minima	Rhynchosia	16SrII-D	Australia	Davis et al. (1997)
				Wilson et al. (2001)
			Jamaica	Dabek (1983)
Rubia tinctorum	Common madder	16SrVI	Iran	Zibadoost and Rastgou (2016)
Scaevola taccada	Beach naupaka	16SrII	Oman	Al-Zadjali et al. (2012)
Sclerocarpus africanus	African bonebract	16SrI	India	Nabi et al. (2015b)
Scoparia dulcis	Licorice weed	16SrXXII-B	Côte D'Ivoire	Arocha Rosete et al. (2016)
Senecio jacobaea	Common ragwort	16SrI	United Kingdom	Reeder and Arocha (2008)
Senna obtusifolia	Sicklepod	16SrII	Australia	Schneider et al. (1999)
Setaria viridis	Green foxtail	16SrXII-A	Italy	Credi et al. (2006)
Sida cordifolia	Flannel weed	16SrII-D	Australia	Davis et al. (1997)
Silene alba	White campion	16SrXII-A	Italy	Credi et al. (2006)
Silene vulgaris	Bladder campion	16SrXII-A	Italy	Berger et al. (2009)
Silene niceensis		16SrI-B	Italy	Cozza et al. (2008)
Solanum nigrum	Black nightshade	16SrII-E	Italy	Tolu et al. (2006)
		16SrXII-A	Spain	Batlle et al. (2000)
Sonchus oleraceus	Common sow thistle	16SrXII-A	Italy	Credi et al. (2006)
Sophora alopecuroides		16SrXII-A	Iran	Allahverdi et al. (2014)
Sorghum halepense	Johnson grass	16SrVI	Iran	Zibadoost and Rastgou (2016)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Sorghum stipoideum		16SrXI	Australia	Tran-Nguyen et al. (2000)
Sorghum versicolor	Wild sorghum	16SrXI	Africa	Asudi et al. (2016)
Spermacocci sp.		16SrII	Australia	Schneider et al. (1999)
Sporobolus pyramidalis	Drop-seed grass	16SrXI	Africa	Asudi et al. (2016)
Stachytarpheta indica		16SrXXII-B	Côte D'Ivoire	Arocha Rosete et al. (2016)
Stachytarpheta jamaicensis	Blue snakeweed		India	Pallavi et al. (2011)
Stellaria media	Common chickweed	16SrI	Germany	Schneider et al. (1997)
Stylosanthes hamata	Cheesytoes	16SrII	Australia	Schneider et al. (1999)
Stylosanthes scabra	Scabrous stylo	16SrII	Australia	Davis et al. (1997) Schneider et al. (1999) Schneider et al. (1999)
Synedrella nodiflora	Nodeweed	16SrIV	Jamaica	Brown et al. (2008a)
Taraxacum officinale	Dandelion	16SrXII-A	Italy	Credi et al. (2006) Berger et al. (2009)
Tephrosia purpurea	Wild indigo	16SrII	India	Yadav et al. (2014) Thorat et al. (2016)
Trichodesma zeylanicum	Cattle bush	16SrII	India	Thorat et al. (2016)
Trifolium repens	White clover	16SrI-C	Canada Germany China	Lee et al. (1992) Schneider et al. (1997) Wu et al. (2010)
Urtica dioica	Stinging nettle	16SrXII-A 16SrXII-H	Italy Austria	Credi et al. (2006) Berger et al. (2009) Aryan et al. (2014)
Urtica urens	Dwarf nettle	16SrXII-A	Italy	Berger et al. (2009)
Vernonia cinerea		16SrIV	Jamaica	Brown et al. (2008b)
Veronica didyma	Veronica	16SrI	China	Wu et al. (2010)
Vigna lanceolata	Maloga bean		Australia	Schneider et al. (1999)
Vigna luteola	Dalrymple vigna	16SrII-D	Australia	Davis et al. (1997)
Vigna trilobata	African gram	16SrII-D	Australia	Davis et al. (1997)

(continued)

Table 11.1 (continued)

Genus and species	Common name	Ribosomal group/ subgroup	Country	Reference
Waltheria indica	Sleepy morning	16SrII	Australia	Schneider et al. (1999)
Whiteochloa biciliata	Mauve sandgrass	16SrXI	Australia	Blanche et al. (2003)
Whiteochloa capillipes		16SrXI	Australia	Schneider et al. (1999)
Whiteochloa cymbiformis		16SrXI	Australia	Blanche et al. (2003)
				Tran-Nguyen et al. (2000)

phytoplasma was identified in *Senecio jacobaea* (common ragwort) with little leaf, chlorosis, and proliferation of axillary shoots symptoms (Reeder and Arocha 2008).

In Lithuania, poa stunt (PoaS) phytoplasma and festuca yellow (FesY) phytoplasma were detected in *Poa pratensis* (common meadow grass) and *Festuca arundinacea* (tall fescue) and identified as members of subgroup 16SrI-C (Valiūnas et al. 2007).

In India, AY phytoplasma was detected in *Ageratum conyzoides* (goat weed) collected near sugarcane fields showing little leaf symptoms and yellowing of leaf lamina, *Phalaris minor*, *Cannabis sativa* (Fig. 11.1b), *Parthenium hysterophorus* with virescence and witches' broom (Fig. 11.1f), *Crotalaria tetragona* with witches' broom, *C. spectabilis*, and *Achyranthes aspera* (Raj et al. 2008a, b, 2009a; Baiswar et al. 2010; Kumar et al. 2010; Tiwari et al. 2012; Mall et al. 2015; Nabi et al. 2015a; Rao et al. 2017b). *C. spectabilis* (showy rattlebox) is used as a green manure crop to improve soil properties in India where it is a native plant, like in Malay Peninsula. It has been introduced into other areas, such as the USA and the Pacific Islands, where the plant grows like a weed and invades cultivated fields. Nabi et al. (2015b) and Rao et al. (2017a) determined that the weeds, *Sclerocarpus africanus* and *Ocimum canum* (Fig. 11.1a), showing little leaf and witches' broom symptoms collected in Kushinagar and Gorakhpur, India, are alternative natural hosts for sesame phyllody phytoplasma, subgroup 16SrI-B. Also for the first time in India, the typical phytoplasma symptoms of little leaf, yellowing, chlorosis, witches' broom, and stunted growth were observed on the commonly occurring weed *Acalypha indica* (Tiwari et al. 2017). Based on the 16S rRNA gene sequence and virtual RFLP, the *A. indica* phytoplasma was identified as '*Ca*. P. asteris', 16SrI-B subgroup. In *Phyllanthus niruri*, a common weed with medicinal uses in India, symptoms such as yellowing, little leaf, proliferation of axillary shoots, rosetting, and stunted growth were observed, and phytoplasma bodies were first detected using transmission electron microscopy by Samad et al. (2004) and later by sequence analysis of the 16S rRNA gene where '*Ca*. P. asteris' was identified (Chaube et al. 2015). A '*Ca*. P. asteris'-related strain was reported affecting *Mikania* sp. from Bangladesh (Kelly et al. 2009).

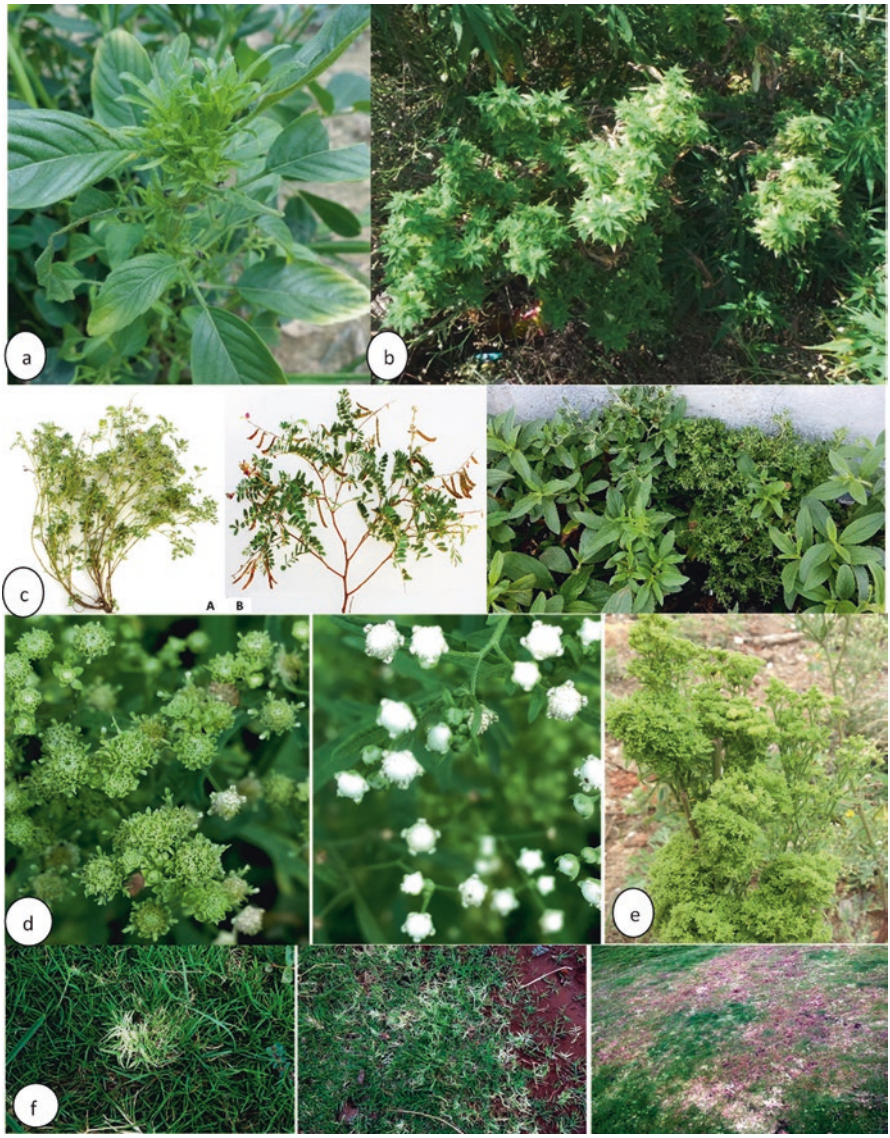

Fig. 11.1 Little leaf and witches' broom of *Ocimum canum* (**a**); witches' broom in *Cannabis sativa* (**b**); typical witches' broom symptoms in *Tephrosia purpurea* (**c**); little leaf disease symptoms in *Trichodesma zeylanicum* (cattle bush) (**d**); phyllody and witches' broom in *Parthenium hysterophorus* (**e**); white leaf in Bermuda grass (**f**)

In China, several weeds were identified as hosts of the wheat blue dwarf phytoplasma (WBD), 16SrI-C subgroup, found near wheat fields. These weeds were redroot amaranth (*Amaranthus retroflexus*), corn gromwell (*Lithospermum arvense*), flixweed-tansy mustard (*Descurainia sophia*), wormseed mustard (*Erysimum chei-*

ranthoides), goat grass (*Aegilops squarrosa*), wild oat (*Avena fatua*), stink grass (*Eragrostis cilianensis*), volunteer wheat seedlings (*Triticum aestivum*), white clover (*Trifolium repens*), and veronica (*Veronica didyma*) (Wu et al. 2010). The invasive weed "epazote" (*Chenopodium ambrosioides*) exhibiting small leaves and fasciation was found in a pepper field in Qijiang County (China), and in it a phytoplasma related to the 16SrI-B group was identified (Li et al. 2012). Also 16SrI-B-related phytoplasmas were found in *Melochia corchorifolia*, a common invasive weed in China, with witches' broom, virescence, and phyllody symptoms (Chen et al. 2017). *Mimosa pudica* is a perennial, widespread serious weed in cultivated grasslands and plantation crops such as coffee, tea, and oil palm, and '*Ca*. P. asteris' was detected in plants with leaf yellowing, little leaf, and proliferation of axillary shoot symptoms in Indonesia (Boa et al. 2010).

In Canada Lee et al. (1992) reported a phytoplasma infecting *Trifolium* sp. (Fabaceae) with clover phyllody symptoms and identified the agent as a 16SrI-C aster yellows group member.

11.3 Phytoplasmas in 16SrII Group (Peanut Witches' Broom)

In Italy, a 16SrII-A subgroup phytoplasma was detected in *Picris echioides* (bristly oxtongue) sampled inside commercial vineyards affected by grapevine yellows (Marcone et al. 1997b).

Tolu et al. (2006) surveyed 14 different chlorotic and stunted weed species growing within a 10-year-old vineyard affected by "bois noir" disease in Italy and identified phytoplasmas belonging to the 16SrII-E subgroup in three *Calendula arvensis*, one *Solanum nigrum* and in one *Chenopodium* sp. samples.

In Saudi Arabia, around 25% of lime trees were declining in 2007, and a survey detected phytoplasmas belonging to the 16SrII group in lime trees; in the weeds, *Chenopodium murale*, *Plantago lanceolate*, and *Convolvulus arvensis*; and in the insect, *Empoasca decipiens* (Alhudaib et al. 2009). In Oman, in *Polygala mascatense* with stunted small leaves, bushy growth, and phyllody symptoms, and in *Scaevola taccada* (beach naupaka) showing witches' broom symptoms, a member of the 16SrII group was detected (Livingston et al. 2006; Al-Zadjali et al. 2012). In *Achyranthes aspera* (an annual herb that grows wild in India), the agent of lime witches' broom disease was detected in the Sultanate of Oman (Moghal et al. 1998). In Iran, peanut witches' broom-related phytoplasmas (16SrII) were detected in *Calendula officinalis* (pot marigold) with phyllody symptoms; in *Prosopis farcta* with small leaves, shortened internodes, proliferation of axillary buds, and bushy growth habit; and in *Cardaria draba* with dwarfing, virescence, phyllody, and infertile flowers (Esmailzadeh Hosseini et al. 2011a, b).

In India, phytoplasmas belonging to group 16SrII were detected in *Amaranthus* sp. with yellowing symptoms, in *Parthenium hysterophorus*, and in *Oplismenus*

burmannii (Arocha et al. 2008; Mall et al. 2015). The 16SrII subgroups C and D phytoplasma strains were discovered in all symptomatic *P. hysterophorus* samples and in the previously reported insect vector, *Orosius albicinctus* (Cicadellidae), and other collected Hemipteran insects collected from the same sampling site (Yadav et al. 2015). The 16SrII group phytoplasmas were also found associated with *Crotalaria pallida*, commonly used as green manure in India (Yadav et al. 2016).

In China, a phytoplasma belonging to the 16SrII-A subgroup was detected for the first time in *P. hysterophorus* by Li et al. (2011). This finding was also confirmed by Cai et al. (2016) who identified the same phytoplasma in this well-known invasive weed as well as in symptomatic plants of cowpea, sword bean, string bean, tomato, lettuce, and water spinach which were extensively invaded by *P. hysterophorus*. A new phytoplasma strain classified as a member of subgroup 16SrII-M was detected in *Tephrosia purpurea* (wild indigo), a common weed throughout the Indian subcontinent, collected from Maharashtra, India (Fig. 11.1d). The delineation to subgroup level was achieved using 16S rRNA gene sequencing followed by RFLP analyses (Yadav et al. 2014). During a field survey in India, symptoms of little leaf, phyllody, stunting, and branch proliferation were observed on the common invasive weeds, *Cleome viscosa* (tick weed), *Trichodesma zeylanicum* (cattle bush) (Fig. 11.1e), and *Tephrosia purpurea* (wild indigo), from the same or adjacent fields where symptomatic *Sesamum indicum* (sesame), *Vigna unguiculata* (cow pea), *Phaseolus vulgaris* (French bean), *Dendrocalamus strictus* (bamboo), and *Carica papaya* (papaya) plants were found positive for peanut witches' broom-related phytoplasmas (16SrII). On the basis of 16S rRNA gene sequences, *T. zeylanicum* and *T. purpurea* were infected with phytoplasmas belonging to the 16SrII-C subgroup, while in *C. viscosa* a phytoplasma of the 16SrII-D subgroup was identified (Thorat et al. 2016).

In Australia, tomato big bud, sweet potato little leaf, pigeon pea little leaf, *Waltheria* little leaf, and *Bonamia* little leaf phytoplasmas (all members of 16SrII-D subgroup differentiated by the 16S rRNA spacer region) were detected in more than 40 different plant species. In particular tomato big bud phytoplasma (TBB) was identified in *Gerbera* sp., *Guizotia abyssinica* (niga), *Euphorbia milii*, *Alysicarpus rugosus* (rough chainweed), *Crotalaria novae-hollandiae* (new Holland rattlepod), *Crotalaria* sp., *Macroptilium atropurpureum* (purple bean), *M. lathyroides* (phasey bean), *Rhynchosia minima* (rhynchosia), *Stylosanthes scabra* (scabrous stylo), *Trifolium repens* (white clover), *Vigna luteola* (dalrymple vigna), *V. trilobata*, *Sida cordifolia* (flannel weed), *Phlox sp.* (perennial phlox), *Brugmansia candida* (angel's trumpet), *Physalis minima* (wild gooseberry), *Cynodon dactylon* (Bermuda grass), *Cenchrus ciliaris*, *Eragrostis falcata*, *Ptilotus distans*, *Emilia sonchifolia*, *Macroptilium bracteatum*, *Stylosanthes scabra*, *Goodenia* sp., *Ipomoea plebeia* (bell vine), *Crotalaria goreensis* (blunt bird flower), and *Eriachne obtusa* (Davis et al. 1997; Schneider et al. 1999; Tran-Nguyen et al. 2000). Sweet potato little leaf phytoplasma (variant grafted on vinca, SPLL-V4) was detected in *Cyanthillium cinereum*, *Cleome viscosa*, *Senna obtusifolia*, *Phyllanthus maderaspanatus*, *Aeschynomene indica*, *Aphyllodium* sp., *Arachis pintoi*, *Cajanus marmoratus*, *Crotalaria brevis*, *C. crispata*, *Desmodium intortum*, *Indigofera colutea*,

Macroptilium gracile, *Stylosanthes hamata*, and *S. scabra*. Pigeon pea little leaf phytoplasma (PLL) was detected in *Crotalaria spectabilis*, *Arachis pintoi*, *Macroptilium bracteatum*, and *Stylosanthes scabra*. Waltheria little leaf (WaLL) phytoplasma was detected in *Spermacocci* sp. and *Waltheria indica*. *Bonamia* little leaf (BoLL) phytoplasma, a phytoplasma belonging to group 16SrII with a unique RFLP profile compared to other members of this ribosomal group, was detected in *Bonamia pannosa* (Schneider et al. 1999).

Also in Australia, Wilson et al. (2001) tested non-crop species, associated with sesame (*Sesamum indicum*), mung bean (*Vigna radiata*), and peanut (*Arachis hypogaea*) crops, for phytoplasma presence. SPLL-V4 phytoplasma was identified in *Aeschynomene americana* (American jointvetch), *Alysicarpus vaginalis* (alyce clover), *Centrosema pascuorum* (cavalcade), *Crotalaria goreensis* (gambia pea), *Medicago sativa* (lucerne), *Rhynchosia minima* (rhynchosia), and *Mitracarpus hirtus* (with symptoms of little leaf). PLL phytoplasma was identified in *Mitracarpus hirtus* with symptoms of bunching/little leaf, while WaLL phytoplasma was identified in *Pterocaulon* sp. with symptoms of yellowing/rosette.

In Ethiopia, Bekele et al. (2011) identified a phytoplasma belonging to the 16SrII group in *Parthenium hysterophorus*.

11.4 Phytoplasmas in 16SrIII Group (X-Disease)

In the United Kingdom, 16SrIII phytoplasmas were identified in *Delphinium* sp. with severe phyllody, virescence, and proliferation symptoms (Harju et al. 2008). In the USA, a phytoplasma assigned to the western X-disease group was identified in *Conyza* (*Erigeron*) *canadensis* (horseweed) collected next to an apple orchard (Schneider et al. 1997). Palermo et al. (2004) found 16SrIII phytoplasma in *Cirsium* spp. and *Convolvulus arvensis* in Hungarian vineyards, while Rančić et al. (2005) found the same phytoplasma in *Cirsium arvense* in Serbia. In Australia, poinsettia branching-induced phytoplasma (PoiBI, member of the 16SrIII-H subgroup) was detected in wild *Euphorbia pulcherrima* plants (Schneider et al. 1999).

11.5 Phytoplasmas in Groups 16SrIV (Coconut Lethal Yellowing), 16SrV (Elm Yellows), 16SrVI (Clover Proliferation), 16SrVII (Ash Yellows), 16SrIX (Pigeon Pea Witches' Broom), and 16SrX (Apple Proliferation)

Brown et al. (2008b) sampled *Vernonia cinerea* (L.) (Asteraceae) plants, a prevalent dicotyledonous weed inside coconut farms in Jamaica, and even though the plants showed no symptoms, 44.9% (53 out of 118 tested) of them tested positive for phytoplasma. RFLP analysis identified the detected phytoplasmas as coconut lethal

yellowing phytoplasma, from ribosomal group 16SrIV. The same authors also found this phytoplasma in the weeds, *Emilia fosbergii* and *Synedrella nodiflora* (Brown et al. 2008a).

In China, a phytoplasma belonging to the 16SrV-B ribosomal subgroup was detected in amaranth (*Amaranthus retroflexus* L.) and in *Phragmites australis* (Poaceae, a widely distributed weed species in China), both with typical witches' broom symptoms, (Yang et al. 2011; Li et al. 2013). A witches' broom disease on *Cannabis* sp. was earlier found to be associated with a phytoplasma of elm yellows group (16SrV) in China (Zhao et al. 2007). In Iran, phytoplasmas belonging to ribosomal group 16SrVI were detected in *Sorghum halepense* (Johnson grass), *Conyza canadensis* (Canadian horseweed), and *Rubia tinctorum* (common madder) with symptoms of yellowing, little leaf, and witches' broom (Zibadoost and Rastgou 2016). In India, a phytoplasma designated as a member of the ribosomal group 16SrVI was detected in *Datura stramonium* with symptoms of witches' broom and little leaf, in *D. inoxia* with proliferation of branches, shortened internodes, and smaller leaves and in *Calotropis gigantea* (crown flower) with symptoms of leaf yellowing (Raj et al. 2009b; Madupriya et al. 2010; Singh et al. 2012; Mall et al. 2015). In Brazil, *Erigeron* sp. with symptoms of witches' broom and chlorosis were found to be infected with new phytoplasma subgroups B and D that fall within group 16SrVII (Barros et al. 2002; Flôres et al. 2015). Symptoms of a phytoplasma disease including phyllody, virescence, witches' broom, and little leaf were observed on *Bidens alba* growing like a weed in citrus orchards of Hormozgan Province, Iran, and after analyses, a phytoplasma related to '*Ca*. P. phoenicium' (16SrIX group) was detected (Hemmati et al. 2017). In Germany, apple proliferation phytoplasma was detected in a single symptomatic *Convolvulus arvensis* (field bindweed) plant out of 25 collected in or around apple/stone fruit orchards (Schneider et al. 1997).

11.6 Phytoplasmas in 16SrXI Group (Rice Yellow Dwarf)

The 16SrXI or rice yellow dwarf group consists of subgroup A, which includes rice yellow dwarf phytoplasma (RYD) and napier grass stunt phytoplasma (NGS); subgroup B, which includes sugarcane white leaf phytoplasma (SCWL) and sugarcane grassy shoot phytoplasma (SCGS); and a leafhopper-borne (BVK) phytoplasma included in subgroup C (Lee et al. 2000; Jones et al. 2004). In Italy, phytoplasmas belonging to the sugarcane white leaf group (16SrXI-B) were detected in *Picris echioides* (bristly oxtongue) collected in an apple orchard, *Crepis setosa* (hawksbeard) collected in alfalfa fields, *Knautia arvensis* (field scabious) collected in brushwood areas, and *Echium vulgare* (blueweed) collected in vineyards affected by grapevine yellows (Schneider et al. 1997; Marcone et al. 1997b). In Myanmar, goosegrass white leaf (GGWL) phytoplasma was detected in *Eleusine indica* (goosegrass). This phytoplasma is closely related to SGS phytoplasma (Win et al. 2013).

In Australia, sorghum grassy shoot (SGS) phytoplasma was detected and identified for the first time in S*orghum stipoideum* and *Whiteochloa capillipes* by Schneider et al. (1999) that according to tentative classification by *i*Phyclassifier is a member of the 16SrXI-C ribosomal subgroup (Zhao et al. 2009). Tran-Nguyen et al. (2000) also found SGS phytoplasma in *S. stipoideum* and *W. cymbiformis*. Later, during a generic survey of grasses in Australia, Blanche et al. (2003) detected a SGS-related phytoplasma in *W. cymbiformis*, *W. biciliata*, *Dactyloctenium aegyptium*, *D. radulans*, and *Chloris inflata*. They also tried to associate symptoms with the phytoplasmas identified, but it wasn't possible due to a number of symptomless plants testing positive for phytoplasma.

In Africa, Obura et al. (2011) detected a phytoplasma in *Hyparrhenia rufa* (thatching grass which is common in the tropics) which were stunted and appeared bushy, with small white leaves, and identified it as a member of the 16SrXI ribosomal group. Later in East Africa, Asudi et al. (2016) tested plants from 33 grass species collected from fields bordering farms of napier grass (*Pennisetum purpureum*), an important fodder for livestock. Besides '*Ca*. P. cynodontis', they identified a phytoplasma related to NGS (16SrXI-A) in the following 11 grass species: *Coix lacryma-jobi* (otiro), *Chloris gayana* (rhodes grass), *Digitaria scalarum* (couch grass), *Enteropogon macrostachyus* (bush rye), *Eleusine indica* (goosegrass), *Hyparrhenia cymbaria* (thatch grass), *H. rufa* (thatch grass), *Sorghum versicolor* (wild sorghum), *Sporobolus pyramidalis* (drop-seed grass), *Cynodon dactylon* (Bermuda grass) and *Brachiaria brizantha* (signal grass), and GGWL phytoplasma (16SrXI-C) in two wild grass species (*B. brizantha* and *S. pyramidalis*).

In Germany, *Cirsium arvense* (Canada thistle) collected in or around apple/stone fruit orchards were found to be infected with cirsium phyllody (CIRP) phytoplasma, a phytoplasma closely related to members of the SCWL group, however sharing only 96.9 and 96.7% 16S rRNA sequence identity to both SCWL and BVK phytoplasmas, respectively (Schneider et al. 1997). A new taxon has therefore been introduced, '*Ca*. P. cirsii', comprising the phytoplasma found in *C. arvense* and *Dahlia* sp. that induces symptoms of yellowing, stunting, inflorescence, and proliferation in samples collected from the Czech Republic. Phytoplasmas belonging to this taxon are members of subgroup 16SrXI-E and appear to only infect dicotyledonous plants (Šafářová et al. 2016).

11.7 Phytoplasmas in 16SrXII-A Group ("Stolbur" Group)

"Stolbur" phytoplasma in grapevine induces a disease called "bois noir" (BN) that is one of the most investigated phytoplasma diseases in Europe. In order for BN to spread, herbaceous host plants, which serves as a phytoplasma reservoir, and insect vectors need to be present. Stinging nettle (*Urtica dioica*) and bindweed (*Convolvulus arvensis*) were in most cases found to be the main phytoplasma source. In Slovenia, Mehle et al. (2011) detected and identified "stolbur" in 43% of tested bindweed

samples. Marcone et al. (1997b) tested six weed species from Italy that had yellowing of the leaves and among other things identified a new "stolbur" group in field bindweed, while Palermo et al. (2004) detected "stolbur" on stinging nettle in Hungarian vineyards.

According to the sequence and RFLP profile of the *tuf* gene (elongation factor Tu), Langer and Maixner (2004) assigned "stolbur" phytoplasma to two main genetic types, tuf type I (tuf-type a) and tuf type II (tuf-type b) that were involved in different natural epidemic cycles. Strains belonging to tuf-type a are predominately spread via *U. dioica* in Germany, while tuf-type b strains were less specific and were found in *C. arvensis*, *C. sepium*, *Prunus spinosa*, and *Solanum nigrum*. A third type, tuf-type III (tuf-type c) has only been detected in *C. sepium* in the Mosel area in Germany. Fialová et al. (2009) found tuf-type b strains also to be present in other weedy plants such as *Amaranthus retroflexus*, *Cirsium arvense*, and *Datura stramonium*, as well as in *U. dioica* collected in intensive vegetable crop fields and in two vineyards in the Czech Republic. In Austria, between 2003 and 2008, only tuf-type b strains were found to be present in *C. arvensis* and grapevine, while infections of *U. dioica* were rare (Riedle-Bauer et al. 2006, 2008; Tiefenbrunner et al. 2007). Aryan et al. (2014) found an intermediate tuf-type, on the basis of the sequence of *tuf* gene, called tuf-type b2 and discovered that all "stolbur" phytoplasmas from nettle in the studied area belonged to the new tuf-type b2.

Berger et al. (2009) surveyed, among other things, 516 herbaceous plants of 41 potential host species belonging to 21 families, in 15 BN-affected commercial vineyards from South Tyrol, Northern Italy, over 4 years as part of a monitoring study. The "stolbur" phytoplasma was detected in seven species belonging to six families: *C. arvensis* (Convolvulaceae), *Echium vulgare* (Boraginaceae), *Polygonum aviculare* (Polygonaceae), *Silene vulgaris* (Caryophyllaceae), *Taraxacum officinale* (Asteraceae), and the two Urticaceae species *U. dioica* and *U. urens*. For *C. arvensis*, 25.1% (45 out of 179) tested positive for "stolbur" phytoplasma, as well as 4.5% (5 out of 111) of stinging nettle samples and the single *U. urens* (dwarf nettle) sample. Furthermore, positive samples of *C. arvensis*, *E. vulgare*, *P. aviculare*, *S. vulgaris*, and *T. officinale* were assigned to tuf-type b, while positive samples from both *Urtica* plants were assigned to tuf-type a.

Credi et al. (2006) surveyed 162 non-crop native plant samples, consisting of 30 plant species, in vineyards in the region of Emilia-Romagna, Italy, and found that 48.1% samples tested positive for "stolbur" phytoplasma. The 18 positive weed species belonged to the following 13 families: *Amaranthus retroflexus* (Amaranthaceae), *Silene alba* (Caryophyllaceae), *Chenopodium album* (Chenopodiaceae), *Artemisia vulgaris*, *Cirsium arvense*, *Picris echioides*, *Sonchus oleraceus*, *Taraxacum officinale* (Compositae), *Calystegia sepium*, *Convolvulus arvensis* (Convolvulaceae), *Mentha arvensis* (Labiateae), *Medicago sativa* (Leguminosae), *Malva sylvestris* (Malvaceae), *Plantago lanceolata* (Plantaginaceae), *Setaria viridis* (Poaceae), *Potentilla reptans* (Rosaceae), *Datura stramonium* (Solanaceae), and *Urtica dioica* (Urticaceae). These infected weeds included 5 annual, 1 biennial, and 12 perennial species which represents a huge phytoplasma reservoir. Plant symptoms consisted

of stunting, rosetting, chlorosis, leaf malformation, little leaf, leaf yellowing, reddening, and necrosis while some species, *A. retroflexus* (redroot pigweed), *C. album* (lambsquarter), and *U. dioica* (stinging nettle), were symptomless. Batlle et al. (2000) also found "stolbur"-positive *C. arvensis*, *Lavandula officinalis*, *Polygonum convolvulus*, and *Solanum nigrum* in three regions of Northeast Spain. They also found *Plantago lanceolata* being sporadically infected. Allahverdi et al. (2014) reported '*Ca*. P. solani' (16SrXII-A group, "stolbur") affecting *Sophora alopecuroides* in Iran where it is considered an invasive weed.

In *C. arvensis* (bindweed), a well-known host of "stolbur" phytoplasma, a phytoplasma that could not be assigned to any previously reported group or subgroup from time to time could be found in Italy. The symptoms observed on the diseased bindweed were undersized leaves, shoot proliferation, and yellowing (Marcone et al. 1997b; Martini et al. 2008). After phylogenetic analyses of the amplified 16S rRNA gene and 16S–23S rRNA spacer region of strains from Italy, Serbia, Bosnia and Herzegovina, and Germany, this phytoplasma was classified into a new subgroup inside the 16SrXII group, subgroup 16SrXII-H. This phytoplasma shares 97.2% similarity of its 16S rRNA gene sequence with "stolbur" phytoplasma (16SrXII-A) and 97.1% with '*Ca*. P. fragariae' (16SrXII-E). RFLP patterns of R16F2n/R16R2 amplicons are most similar to those of phytoplasmas belonging to subgroups 16SrI-C and 16SrXII-A, but RFLP analyses using *Alu*I, *Hae*III, and *Tru*I restriction enzymes could clearly distinguish it (Martini et al. 2012). Aryan et al. (2014) identified '*Ca*. P. convolvuli' (16SrXII-H) in some stinging nettles, and almost all bindweed samples tested positive for phytoplasma in a survey for the presence of BN in Austrian vineyards.

11.8 Phytoplasmas in 16SrXIV Group (Bermuda Grass White Leaf)

Bermuda grass white leaf (BGWL) phytoplasma is the agent of a white leaf disease in *Cynodon dactylon* L. (Bermuda grass) (Fig. 11.1d), and it was first reported in Taiwan by Chen et al. (1972). So far, BGWL phytoplasma has been reported in Italy (Marcone et al. 1997a), Serbia, Albania (Mitrović et al. 2015), Turkey (Çağlar et al. 2013a), Saudi Arabia (Omar 2016), Iran (Salehi et al. 2009), Pakistan (Zahoor et al. 1995), India (Rao et al. 2007; Snehi et al. 2008; Kumar et al. 2015; Mall et al. 2015), Myanmar (Win et al. 2013), Thailand (Sarindu and Clark 1993; Wongkaew et al. 1997; Sdoodee et al. 1999), Malaysia (Nejat et al. 2009a, b), Singapore (Koh et al. 2008), Australia (Schneider et al. 1999; Tran-Nguyen et al. 2000, Blanche et al. 2003), Cuba (Arocha et al. 2005), and Africa (Dafalla and Cousin 1988; Obura et al. 2010; Asudi et al. 2016).

The most frequent symptom of BGWL phytoplasma is extensive chlorosis, but other symptoms such as proliferation of axillary shoots, bushy growing habit, small leaves, shortened stolons and rhizomes, stunting, and in the end death of the host

plant can be present (Marcone et al. 2004). The phytoplasma associated with this disease is a member of the 16SrXIV-A subgroup, together with the phytoplasmas of white leaf diseases of other gramineous plants such as *Brachiaria distachya* (brachiaria grass), *Poa annua* (annual blue grass), and *Dactyloctenium aegyptum* (crowfoot grass) (Lee et al. 1997, 1998a, 2000; Seemüller et al. 1998; Sdoodee et al. 1999). Another phytoplasma closely related or identical to BGWL is the agent of Australian cynodon white leaf (CWL) disease (Schneider et al. 1999; Tran-Nguyen et al. 2000). A phytoplasma associated with carpet grass white leaf (CGWL) on *Axonopus compressus* is also considered to be closely related to BGWL (Schneider et al. 1999).

Agents of monocot diseases like sugarcane white leaf (SCWL), sugarcane grassy shoot (SCGS), rice yellow dwarf (RYD), and sorghum (*Sorghum stipoideum*) grassy shoot (SGS) belonging to 16SrXI group ('*Ca*. P. oryzae') are distantly related to this group (they share 98.2–98.5% 16S rRNA identity) (Firrao et al. 2005). All these phytoplasmas form a so-called SCWL branch inside the phytoplasma clade, and in earlier years they were classified as members of the 16SrXI group, with BGWL and closely related strains being separated in subgroup 16SrXI-C (Lee et al. 1997). Marcone et al. (2004) performed the taxonomic study and showed that according to the 16S rDNA gene and 16S–23S rDNA spacer region sequences, serological comparisons, vector transmission, and host-range specificity, BGWL phytoplasma is a discrete taxon at the putative species level and proposed the name '*Ca*. P. cynodontis' for it. They selected BGWL-C1 strain from Italy as the reference strain (GenBank accession number AJ550984). Omar (2016) showed that on the basis of 16S rDNA sequence, the '*Ca*. P. cynodontis' clade was regionally divided into four subclades – two subclades consisting only of strains from Saudi Arabia/Serbia, one of the strains from Italy and Albania, and one of the strains from Myanmar, China, and India what was in concordance with previous work of Salehi et al. (2009) and Mitrović et al. (2015) who classified the strain from Iran into subgroup 16SrXIV-B and strains from Serbia into subgroup 16SrXIV-C.

'*Ca*. P. cynodontis' was associated with many weeds and plant species such as *Dodonaea angustifolia* (sand olive shrub) and *Arundo donax* (giant reed) in Saudi Arabia (Omar 2016); *Dichanthium annulatum* (marvel grass), *Ranunculus sceleratus* with little leaf disease, *Oplismenus burmannii*, *Digitaria sanguinalis* and *D. ciliaris* in India, and *Eleusine indica* (goosegrass) in India and Africa (Rao et al. 2009, 2010, 2011; Singh et al. 2013; Mall et al. 2015; Asudi et al. 2016); *Chrysopogon aciculatus* (golden beard grass) in Myanmar (Win and Jung 2012); *Axonopus compressus* in Singapore and Thailand (Koh et al. 2008; Sunpapao 2016), *Paspalum conjugatum* in Singapore (Koh et al. 2008); and *Brachiaria brizantha* (signal grass) and *Hyparrhenia rufa* (thatch grass) in Africa (Asudi et al. 2016).

In Iran, *Exitianus capicola* was reported as a natural and experimental vector of BGWL agent (Salehi et al. 2009). During a survey in India for potential insect vectors of BGWL phytoplasma, Kumar et al. (2015) found that the leafhopper, *Exitianus indicus*, could be a putative vector since the phytoplasma carried by this insect shared 99% identity of the 16S rRNA gene sequence with BGWL from India and Thailand. To assess the importance of BGWL phytoplasma to agricultural crops such as sugarcane, Khankahdani and Ghasemi (2011) performed serological testing.

According to their results, there was no serological relationship between BGWL and SCWL (sugarcane white leaf), LWB (lime witches' broom), AWB (almond witches' broom), and PY (periwinkle yellowing) phytoplasma. Also, it has been shown that BGWL is not transmitted by the vector of SCWL, *Matsumuratettis hiroglyphicus* (Firrao et al. 2005). On the other hand, Çağlar et al. (2013b) managed to transmit BGWL phytoplasma to wheat plants (*Triticum* spp.) by a root-bridge modality with 30% successful transmission. Even though members of the 16SrXIV group are identical, or nearly identical, on the basis of their 16S rRNA gene sequences and on the basis of their ecological and genetic features, insufficient evidence exists for their relationship. Therefore, Firrao et al. (2005) stated that they should be considered as members of different '*Candidatus* Phytoplasma' species.

In Bermuda grass *Clavibacter xyli* subsp. *cynodontis* can also be detected, and it is thought that this bacterium causes only stunting symptoms. However, when it was detected together with BGWL phytoplasma, the plants showed more severe disease symptoms leading to early death of the plants (Davis et al. 1983). Also spiroplasmas could be detected in Bermuda grass with witches' broom, but they were not apparently associated with this symptom (Chen et al. 1977; Raju and Chen 1980).

11.9 Phytoplasmas in 16SrXXII Group

Very recently a survey was carried out in Grand-Lahou in Côte d'Ivoire where coconut palms are severely affected by a lethal yellowing disease (CILY) associated with the group 16SrXXII-B, '*Ca*. P. palmicola'-related strains. Plant species from the families Poaceae (*Paspalum vaginatum*, *Pennisetum pedicillatum*), Verbenaceae (*Stachytarpheta indica*), Plantaginaceae (*Scoparia dulcis*), Phyllanthaceae (*Phyllanthus muellerianus*), and Cyperaceae (*Diplacrum capitatum*) were positive for the presence of the CILY phytoplasma, suggesting they may have epidemiological implications for disease spread in coconut plants (Arocha Rosete et al. 2016).

11.10 Phytoplasmas in 16SrXXIX Group

Al-Saady et al. (2008) reported '*Ca*. P. omanense' in Italian senna (*Cassia italica*, fam. *Fabaceae*), a native plant from Africa, commonly found throughout the Arabian Peninsula. *C. italica* plants showing witches' broom symptoms were collected in Oman. In Iran, *Convolvulus arvensis* growing in alfalfa fields were found to be infected with phytoplasmas that shared 99% identity with '*Ca*. P. omanense' but were differentiated from it by specific RFLP analyses and were assigned to subgroup 16SrXXIX-B (Esmailzadeh Hosseini et al. 2016a).

11.11 Phytoplasmas in Undesignated Groups

In India, *Stachytarpheta jamaicensis* plants with witches' broom symptoms were confirmed to be infected with phytoplasmas by nested PCR employing universal phytoplasma primers, but they were not identified (Pallavi et al. 2011). In Australia, a new phytoplasma was detected in *Cenchrus setiger* and was named cenchrus bunchy shoot (CBS), as well as detection of *Stylosanthes* little leaf (StLL) in *Stylosanthes scabra* and *Arachis pintoi*, *Galactia* little leaf (GaLL) in *Galactia tenuiflora*, and vigna little leaf (ViLL) in *Vigna lanceolata*. According to *i*Phyclassifier this latter phytoplasma shares 98.2% 16S rDNA sequence identity with '*Ca*. P. omanense', a member of the 16SrXXIX ribosomal group (Schneider et al. 1999; Tran-Nguyen et al. 2000; Zhao et al. 2009).

11.12 Geographic Distribution

In Africa and Oceania (including Australia), phytoplasmas affiliated to a small number of ribosomal groups (three to four) have been detected so far, while in Europe and Asia, numerous phytoplasmas, belonging to more than seven ribosomal groups, were detected (Table 11.2). The wide host range of weeds (18 families in Europe and 22 families in Asia) described on these two continents might be a result of sampling bias, as the two continents have the most detailed record for phytoplasmas on weeds. Phytoplasmas affiliated to ribosomal group 16SrII were detected in Oceania in weeds and wild plants belonging to 13 different families and in Asia belonging to 11 different families. Likewise, "stolbur" phytoplasma (16SrXII-A) was detected in hosts from 14 different families in Europe. These two phytoplasmas have the widest host range among phytoplasmas in weeds. On the other hand, phytoplasmas affiliated to ribosomal groups 16SrXI and 16SrXIV could be found with some exceptions only in family Poaceae regardless of continent where they were detected.

11.13 Conclusion

Wild plants, as natural phytoplasma hosts, are sometimes symptomless, probably due to long coevolution between the host and pathogen. If crop plants are grown in the same environment, this natural epidemiological cycle can branch to cultivated plants as dead-end hosts to form a crop-specific epidemic system. In this way, new diseases of economic importance are emerging (Lee et al. 1998b). In the case that cultivated plants represent a dead-end host, transmission of phytoplasma depends on the presence of wild hosts as a reservoir (source of inoculum). Such diseases can be of high economic impact, and one example is the "stolbur" phytoplasma

Table 11.2 Summary of phytoplasma geographic distribution in weeds and wild plants

Continent	Ribosomal group	Host family	Continent	Ribosomal group	Host family
Europe	16SrI	Asteraceae	Asia	16SrI	Amaranthaceae
		Brassicaceae			Asteraceae
		Caryophyllaceae			Boraginaceae
		Fabaceae			Brasicaceae
		Poaceae			Canabaceae
		Portulacaceae			Euphorbiaceae
	16SrII	Amaranthaceae			Fabaceae
		Asteraceae			Malvaceae
		Solanaceae			Phyllanthaceae
	16SrIII	Asteraceae			Plantaginaceae
		Convolvulaceae			Poaceae
		Ranunculaceae		16SrII	Amaranthaceae
	16SrX	Convolvulaceae			Asteraceae
	16SrXI	Asteraceae			Boraginaceae
		Boraginaceae			Brassicaceae
		Caprifoliaceae			Cleomaceae
	16SrXI-E	Asteraceae			Convolvulaceae
	16SrXII-A	Amaranthaceae			Fabaceae
		Asteraceae			Goodeniaceae
		Boraginaceae			Plantaginaceae
		Caryophyllaceae			Poaceae
		Convolvulaceae			Polygalaceae
		Fabaceae		16SrV	Amaranthaceae
		Lamiaceae			Poaceae
		Malvaceae		16SrVI	Apocynaceae
		Plantaginaceae			Asteraceae
		Poaceae			Poaceae
		Polygonaceae			Rubiaceae
		Rosaceae			Solanaceae
		Solanaceae		16SrIX	Asteraceae
		Urticaceae		16SrXI	Poaceae
	16SrXII-H	Convolvulaceae		16SrXII-A	Fabaceae
	16SrXIV-C	Poaceae		16SrXIV	Poaceae

(continued)

Table 11.2 (continued)

Continent	Ribosomal group	Host family	Continent	Ribosomal group	Host family
Oceania	16SrII	Amaranthaceae			Ranunculaceae
		Asteraceae			Sapindaceae
		Cleomaceae		16SrXXIX	Convolvulaceae
		Convolvulaceae			Fabaceae
		Euphorbiaceae			Apiaceae
		Fabaceae			Phyllanthaceae
		Goodeniaceae			Plantaginaceae
		Malvaceae			Verbenaceae
		Phyllanthaceae	Africa	16SrII	Asteraceae
		Poaceae		16SrXI	Poaceae
		Polemoniaceae		16SrXIV	Poaceae
		Rubiaceae	North America	16SrI	Fabaceae
		Solanaceae		16SrIII	Asteraceae
	16SrIII	Euphorbiaceae		16SrIV	Asteraceae
	16SrXI	Poaceae		16SrXIV	Poaceae
	16SrXIV	Poaceae			Fabaceae
	UDG	Fabaceae	South America	16SrVII	Asteraceae
		Poaceae			

(16SrXII-A, '*Ca*. P. solani'). Natural hosts of "stolbur" are *U. dioica* and *C. arvensis*, while the cultivated hosts are solanaceous crops, grapevine, and corn. "Stolbur"-infected *U. dioica* is usually symptomless and therefore represents an even greater threat to crops. In such cases, weed management by herbicide treatment is an effective method of reducing disease incidence. It is achieved through elimination of the source of inoculum and lowering the density of the vector population (Maixner 2009). Crop-specific epidemic systems are often new epidemiological cycles that evolved from the dead-end host system in the presence of a potentially competent vector. An example of such a system is "flavescence dorée" (16SrV-C/-D), whose epidemiological cycle became independent from its original, natural host. The origin of "flavescence dorée" can now be deduced by analyses of DNA (Arnaud et al. 2007). Although there is no clear recognized role of weeds in this kind of epidemic systems, this underlines the importance of weeds in the emergence of new crop diseases.

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