Chapter 7
Phytoplasma Diseases in Ornamental Crops

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Abstract An extensive and updated review of the literature reporting the phytoplasma associated diseases in a number of ornamental plants and their classification is presented with major emphasis to reports in the main floricultural areas. Symptomatology of phytoplasma diseases is described in the most relevant traditional species as well as in emerging species used in floriculture and gardening worldwide.

Keywords Ornamental species · Phytoplasma · Symptomatology · PCR · RFLP

7.1 Introduction

The phytoplasmas are an important group of pathogens which drastically damage growth and marketing parameters of ornamental plants and affect their commercial value (Chaturvedi et al. 2010a). Many ornamental plants are affected by phytoplasmas that are very often associated with significant economic impacts. The number of phytoplasmas identified in ornamental species has greatly increased over the last decades as a consequence of increased production and worldwide commercial distribution of plant material (consisting of cut flowers, foliage or flowering potted plants, shoots, seeds, bulbs, rhizomes, etc.). In addition, some species and new hybrids are becoming more economically important all over the world, but no information is available regarding susceptibility and/or tolerance to these pathogens. As a consequence, the incidence varies from overall infection due to phytoplasmas frequently found, to those observed only occasionally. The severity of symptoms differs considerably among ornamental species, hybrids, and varieties, ranging from

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malformations and yellowing causing little or no appreciable damage to severe virescence, phyllody, and growth reduction (Lee et al. 1998). Phytoplasma diseases of ornamentals have been described worldwide in a wide range of plant genera, and the associated phytoplasmas belong to 14 different 16S ribosomal groups and to about 30 ribosomal subgroups (Table 7.1).

Table 7.1 Symptomatology, identification, and distribution of phytoplasma diseases occurring in ornamental plant species worldwide

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Adenium obesum (Apocynaceae)	Witches' brooms	Myanmar	16SrII	Win et al. (2012)
	Little leaf	India	16SrI	Raj et al. (2007a)
Allamanda cathartica (Apocynaceae)	Leaf yellowing	India	16SrVI-D	Khasa et al. (2016)
Alstroemeria (Alstroemeriaceae)	Virescence	Italy	16SrI-B	Bertaccini et al. (1996a)
	Deformation and dieback	Mexico		Cervantes-Diaz et al. (2004)
	Little leaf	India	16SrI	Singh et al. (2011)
Anemone coronaria (Ranunculaceae)	Virescence	Italy	16SrI-C	Vibio et al. (1995)
Aquilegia columbine (Ranunculaceae)	Yellows, stunting, virescence, and phyllody	Lithuania	16SrI	Samuitiene et al. (2004)
Aralia cordata/ Japanese spikenard (Araliaceae)	Yellow dwarf	South Korea	16SrIII	Lee et al. (2004)
Argyranthemum frutescens (Asteraceae)	Yellowing	Italy	16SrIX-C	Ferretti et al. (2015)
Asclepias physocarpa (Asclepiadaceae)	Yellowing and stunting	Italy	16SrXII-A	Bertaccini et al. (2006)
Begonia spp. (Begoniaceae)	Stunting and little leaf	Brazil	16SrIII	Ribeiro et al. (2006)
Brachyscome (Asteraceae)	Yellows and witches' broom	India	16SrI	Madhupriya et al. (2013a)
Brugmansia candida (Solanaceae)	Little leaf	Australia	–	Hiruki (1986)
Calendula officinalis (Asteraceae)	Phyllody, virescence, proliferation, and witches' broom	Iran	16SrII-D	Esmailzadeh Hosseini et al. (2016)
		Italy	16SrI	Marcone et al. (1997b)
		Serbia	16SrXII-A	Pavlovic et al. (2014)
Calendula arvensis (Asteraceae)	Stunting	Italy	16SrII-E	Tolu et al. (2006)

(continued)

Table 7.1 (continued)

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Callistephus chinensis/ (China aster) (Asteraceae)	Virescence	Korea	16SrII-A	Win et al. (2011)
	Yellowing and stunting	Iran	16SrI-B	Sichani et al. (2014)
Carpobrotus edulis (Aizoaceae)	Leaf yellowing, little leaf, and reduced size of flowers	India	16SrIX	Shukla et al. (2014)
Cassia italica (Caesalpiniaceae)	Stunting	Oman	16SrXXIX-A	Al-Saady et al. (2008)
Cassia surattensis (Caesalpiniaceae)	Witches' broom	China	16SrV	Hong et al. (2005)
Catharanthus roseus (Apocynaceae)	Little leaf	USA	16SrI-A	Davis et al. (1990)
		Italy	16SrI-B	Parrella et al. (2014)
	Virescence	Argentina	16SrI	Torres et al. (2004)
		Egypt	16SrI	Omar et al. (2008)
		Mexico	16SrXIII-A	Gundersen et al. (1994)
	Witches' broom and virescence	Mexico	16SrIII-J; 16SrI	Poghosyan et al. (2015)
	Virescence and phyllody	Malaysia	16SrXXXII	Nejat et al. (2013)
	Phyllody	India	16SrI	Khurana et al. (1981)
	Yellowing and little leaf		16SrI-C	Chaturvedi et al. (2009b)
Celosia argentea (Amaranthaceae)	Phyllody	Lithuania	16SrI-L; 16SrI-M	Samuitiene and Navalinskiene (2006)
		Iran	16SrI-M	Aldaghi and Bertaccini (2015)
	Leaf malformation	Brazil	16SrIII-J	Eckstein et al. (2012)
	–	Iran	16SrVI	Babaie et al. (2007)
Celosia plumosa & Celosia cristata (Amaranthaceae)	Yellows	Israel	16SrI; 16SrIII	Tanne et al. (2000)
Chionanthus retusus/ snow flower fringe (Oleaceae)	Dwarfing	Korea	16SrI	Lee (2004)
Chrysanthemum morifolium (Asteraceae)	Yellowing, stunting, and dwarfing	South Korea	16SrXII; 16SrI	Chung and Kim (2005), Bongnam et al. (2007), Chung and Hun (2008)
	Flattened stem	China	16SrI	Min et al. (2009)
	Little leaf	India	16SrI	Raj et al. (2007b)

(continued)

Table 7.1 (continued)

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Chrysanthemum coronarium (Asteraceae)	Witches' broom	Japan	16SrI-B	Okuda (1997)
		China		Zhong and Shen (2004)
Chrysanthemum frutescens (Asteraceae)	Yellows	Japan	16SrI-B	Okuda (1997)
		Italy	16SrI-B	Bertaccini et al. (1990a)
Chrysanthemum indicum hybridum (Asteraceae)	Virescence and abnormal growth	Serbia	16SrXII-A	Duduk et al. (2006)
Codiaeum variegatum (Euphorbiaceae)	Leaf yellows and witches' broom	India	16SrI	Tiwari et al. (2014)
		Colombia		Perilla-Henao et al. (2012)
Cosmos bipinnatus (Asteraceae)	Phyllody	Mexico	16SrI-B	Rojas-Martínez et al. (2003a)
Cycas revoluta (Cycadaceae)	Yellowing	India	16SrII	Kumar et al. (2012a)
Cyclamen persicum (Primulaceae)	Virescence	Italy	16SrI-B; 16SrI-C	Alma et al. (2000), Satta et al. (2013)
Cytisus scoparius (Fabaceae)	Witches' broom	Germany	16SrV-C; 16SrI-B	Contaldo et al. (2015b)
Dahlia cultorum (Asteraceae)	Shoot proliferation, narrow leaf, and flower bud deficiency	Poland	16SrI-B; 16SrX-A	Kaminska and Śliwa (2008b)
		Italy	16SrX-A	Marzachì et al. (1999)
Delphinium sp. (Ranunculaceae)	Yellows, stunting, phyllody, and virescence	United Kingdom	16SrIII	Harju et al. (2008)
Daucus carota/Queen Anne's lace (Plumbaginaceae)	Yellows	Canada	16SrI	Chang et al. (2004)
Dendranthema grandiflora (Asteraceae)	Yellow dwarf and witches' broom	South Korea	16SrI; 16SrXII	Chung and Kim (2005)
	Phyllody	India	.	Rani et al. (2014)
Dicentra spectabilis/bleeding heart (Fumariaceae)	Shoot proliferation	Poland	16SrI-B; 16SrI-A	Kaminska et al. (2004)
Dictamnus albus (Rutaceae)	Stunting	USA	16SrIII	Valiunas et al. (2007)
Dimorphotheca sinuata (Asteraceae)	Stunting, virescence, and phyllody	Italy	16SrIX	Marcone et al. (2001)
Duranta repens (Verbenaceae)	Virescence and stunting	India	16SrI	Singh et al. (2011)

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Table 7.1 (continued)

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Echinacea purpurea/purple coneflower (Euphorbiaceae)	Phyllody	USA	16SrI-B	Lee et al. (2008)
	Yellowing, virescence, and phyllody	Slovenia	16SrI	Radisek et al. (2008)
	Virescence, phyllody, malformations, and stunting	Italy	16SrI-B; 16SrIX-C	Bertaccini et al. (2009)
	Flower deformation and pale coloration	Czech Republic	16SrI-C; 16SrIII-B	Franova et al. (2009, 2013)
Erysimum linifolium (Brassicaceae)	Stunting and malformation	Italy	16SrI-B	Paltrinieri et al. (2015)
Euphorbia pulcherrima (Euphorbiaceae)	Branch inducing and stem flat	Italy, USA	16SrIII-H	Bertaccini et al. (1996b), Lee et al. (1997)
		South Korea		Chung and Choi (2010)
Gaillardia sp. (Asteraceae)	–	Iran	16SrI-B	Sichani et al. (2014)
Gentiana scabra/ Japanese gentian (Gentianaceae)	Witches' broom	South Korea	Unclassified	Lee (2004)
Gerbera jamesonii (Asteraceae)	Phyllody	Australia	16SrII-D	Siddique (2006)
	Virescence and phyllody	Italy	16SrI	Spanò et al. (2011)
Gypsophila paniculata (Caryophyllaceae)	Stunting and witches' broom	Israel	16SrII	Gera et al. (2006)
Gladiolus sp. (Iridaceae)	Yellowing and malformation of flower and stunting	Italy, Portugal	16SrI-B	Bertaccini et al. (1990b, 1992b), Louro et al. (1996)
		India	16SrI	Raj et al. (2009)
Helianthus annuus (Asteraceae)	Virescence and phyllody	Argentina	16SrIII-J	Guzman et al. (2014)
	Virescence, phyllody, and	Iran	16SrII-D	Salehi et al. (2015)
	Witches' broom	Iran	16SrII; 16SrVI	Tazehkand et al. (2010)
Helianthus debilis (Asteraceae)	Little leaf	USA	16SrI	Harrison and Helmick (2008)
Hibiscus rosa-sinensis (Malvaceae)	Witches' broom	Brazil	16SrXV-A; 16SrXII-A	Montano et al. (2001, 2011)
	Yellow leaf	India	16SrI	Chaturvedi et al. (2010b)
	Leaf yellowing and phyllody	India	16SrVI-D	Khasa et al. (2016)

(continued)

Table 7.1 (continued)

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Hydrangea macrophylla (Saxifragaceae)	Phyllody virescence	Italy Canada	16SrI-B	Bertaccini et al. (1992a), Duduk et al. (2013)
	Phyllody	Japan	16SrXII-C	Sawayanagi et al. (1999)
			16SrI	Takinami et al. (2013)
	Stunting, virescence, necrosis, and redness of the leaf edge	Italy Bulgaria	16SrI-B; 16SrXII-A	Bertaccini et al. (1995, 2015)
Iberis sempervirens (Brassicaceae)	Stunting	Italy	16SrX; 16SrI-B; 16SrI-A	Contaldo et al. (2015a)
Impatiens balsamina (Balsaminaceae)	Virescence, wrinkled leaves, and stunted internods	China	16SrV-B	Li et al. (2014)
Jasminum sambac/ Arabian jasmine (Oleaceae)	Witches' broom	Oman	16SrII	Al-Zadjali et al. (2007)
		India	16SrXI	Madhupriya et al. (2015)
Koelreuteria paniculata/goldenrain tree (Koelreuteriae)	Stunting	Korea	16SrI	Kamala-Kannan et al. (2010)
Lachenalia aloides (Asparagaceae)	Flower malformation	Italy	16SrI-B	Bellardi et al. (2017)
Lilium longiflorum (Liliaceae)	Virescence	Czech Republic	16SrI	Bertaccini et al. (2005)
	Flattened stem	Korea	16SrXII	Chung and Jeong (2003)
	Zigzag line pattern in leaves	Mexico	16SrI	Cortes-Martinez et al. (2007)
	Flower dropping	Poland	16SrI-B; 16SrXII-A	Bertaccini et al. (2002)
	Leaf scorch	Poland	16SrX-A	Kaminska and Śliwa (2008a)
Ligustrum lucidum/Chinese privet (Oleaceae)	Witches' broom	South Korea	16SrV-B	Lee (2004)
Limonium sinuatum (Plumbaginaceae)	Witches' broom	South Korea	16SrI	Chung and Kim (2005)

(continued)

Table 7.1 (continued)

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Lupinus polyphyllus	Malformations	Italy	16SrXII-A	Bellardi et al. (2013)
Magnolia grandiflora (Magnoliaceae)	Stunting, leaf necrosis, and witches' broom	Poland	16SrI-B; 16SrX-A	Kaminska et al. (2001b)
Matthiola incana (Brassicaceae)	Stunting, malformation, and virescence	Italy	16SrII	Davino et al. (2007)
Mirabilis jalapa (Nyctaginaceae)	Yellowing and general stuntings	Israel	16SrII	Sobolev et al. (2007)
	Little leaf	India	16SrII	Kumar et al. (2012b)
Opuntia ficus-indica (Cactaceae)	Proliferation of cladodes and lack of flowers and fruits	Italy	16SrII-C	Granata et al. (2006), Tessitori et al. (2006)
	Proliferation and stunting of cladodes	USA	16SrI-B; 16SrV-A	Bertaccini et al. (2007)
	Buds proliferation, thickening, and heart-shaping of cladodes	Mexico	16SrI	Zak et al. (2011)
Opuntia cylindrica (Cactaceae)	–	Egypt	16SrII	Omar et al. (2014)
Opuntia monacantha	Shoot proliferation	Lebanon	16SrII	Choueiri et al. (2005)
Pachysandra terminalis/Japanese spurge (Buxaceae)	Yellows	South Korea	16SrI-B	Back et al. (2010)
Petunia hybrida (Solanaceae)	Flat stem	South Korea	16SrI	Chung and Hun (2008)
	Yellows	India	16SrI	Singh et al. (2011)
		Iran	16SrII	Faghihi et al. (2014)
Phlox sp. (Polemoniaceae)	Malformation	Lithuania	16SrI-M	Navalinskiene and Samuitiene (2004)
Portulaca grandiflora (Portulacaceae)	Little leaf	India	16SrVI	Ajaykumar et al. (2007), Samad et al. (2008)
Psylliostachys suworowii (Plumbaginaceae)	Yellows	Canada	16SrI	Chang et al. (2004)

(continued)

Table 7.1 (continued)

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Ranunculus sp. (Ranunculaceae)	Phyllody and virescence	Italy	16SrI-B; 16SrI-C	Bertaccini et al. (1988, 1990b), Parrella et al. (2008)
Rhododendron sp./azalea (Ericaceae)	Witches' broom	Czech Republic	16SrXII-A	Mertelik et al. (2004)
Rosa alba (Rosaceae)	Witches' broom and bud proliferation	Poland	16SrI-B; 16SrX-A	Kaminska and Sliwa (2004)
	Little leaf	India	16SrI	Chaturvedi et al. (2009a)
Saponaria officinalis (Caryophyllaceae)	Witches' broom	India	16SrVI-D	Khasa et al. (2016)
Silene nicaeensis (Caryophyllaceae)	Flower malformation	Italy	16SrI-B	Cozza et al. (2008)
Spartium junceum (Fabaceae)	Witches' broom	Italy, Spain	16SrX-D; 16SrV-C; 16SrI	Marcone et al. (1996), Torres et al. (2002), Contaldo et al. (2015a)
Spiraea salicifolia/ spiraea (Rosaceae)	Stunting	USA	16SrIII-E	Griffiths et al. (1994)
		China	16SrI-B; 16SrV-B	Gao et al. (2007), Li et al. (2010)
Spiraea bumalda (Rosaceae)	Witches' broom	USA	16SrIII	Lockhart et al. (2012)
Solidago virgaurea/ goldenrod (Asteraceae)	Witches' broom	Korea	16SrIII	Lee et al. (1996)
Streblus asper/singhore (Moraceae)	Chlorosis and yellows	India	16SrI	Maurya et al. (2014)
Syringa vulgaris/lilac (Oleaceae)	Witches' broom	USA	16SrVII-A	Griffiths et al. (1999)
		South Korea	16SrV-B	Lee et al. (1996)
Tabebuia pentaphylla (Bignoniaceae)	Witches' broom	Brazil	16SrII	Mafia et al. (2008)
Tagetes erecta (Asteraceae)	Phyllody	Mexico	16SrI-B	Rojas-Martínez et al. (2003b)
	Witches' broom	India	16SrI	Raj et al. (2011)
Trillium spp. (Trilliaceae)	Virescence	Canada	16SrIII-F	Arocha-Rosete et al. (2016)
Veronica scutellata (Scrophulariaceae)	Yellowing and little leaf	United Kingdom	16SrI-A	Jones and Arocha (2006)
Viola tricolor (Violaceae)	Leaf yellows and little leaf	India	16SrI	Shukla et al. (2015)

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Table 7.1 (continued)

Host species/trivial name (family)	Diseases	Country	Phytoplasma group/subgroup	References
Xanthoceras sorbifolia (Sapindaceae)	Leaf rolling	China	16SrI	Zhang et al. (2009)
Zamia furfuracea (Arecaceae)	Yellowing	India	16SrII	Kumar et al. (2012a)
Zinnia elegans (Asteraceae)	Little leaf, yellowing, and phyllody	India	16SrI	Rao et al. (2012)
Zygocactus truncatus (Cactaceae)	Witches' broom	China	16SrII	Cai et al. (2007)

Fig. 7.1 Phytoplasma-infected plant of *E. linifolium* showing symptoms in only a part of shoots. At flowering stage, this affected plant does not bloom

7.2 Aegean Wallflower (*Erysimum linifolium* L.; sin. *Cheiranthus linifolium* L.)

Aegean wallflower (Brassicaceae), native to the Mediterranean region, is an evergreen perennial ornamental shrub used in rock gardens or in mixed garden borders. In 2012, a phytoplasma-like disease was observed for the first time in pot plants by an ornamental grower in the Albenga area (Liguria region; northern Italy) (Paltrinieri et al. 2015). Symptomatic *E. linifolium* showed reduced leaf size, rosetting, and stunting; in some cases, shortening of internodes and growth reduction occur in only part of the plant (Fig. 7.1). An increasing percentage of symptomatic plants were found at the flowering stage, when affected plants did not bloom. Phytoplasmas belonging to subgroup 16SrI-B ('*Candidatus* Phytoplasma asteris') were detected by nested PCR followed by RFLP analyses on both the 16S rRNA and *tuf* genes.

Symptomatology associated with aster yellows (AY) presence in *E. linifolium* is very severe, probably due to becoming infected when the plants are in early growth stages. In 2010, phytoplasmas belonging to 16SrII group (‘*Ca. P. aurantifolia*’) were detected in *E. cheiri* (sin. *C. cheiri*), a different species cultivated in southeastern Iran, showing witches’ broom and phyllody (Tazehkand et al. 2010).

7.3 *Allamanda cathartica* L.

A. cathartica (Apocynaceae), commonly called golden trumpet or common trumpet vine, was observed in India showing leaf yellowing symptoms, and phytoplasmas belonging to 16SrVI group (‘*Ca.* P. trifolii’-related) were detected (Khasa et al. 2016).

7.4 *Alstroemeria* spp.

Aster yellows (16SrI) phytoplasmas were detected in *Alstroemeria* (Alstroemeriaceae) plants growing under greenhouse conditions and showing virescence symptoms in both Italy and the Netherlands (Bertaccini et al. 1996a). Phytoplasmas of the same ribosomal group were identified in malformed plants in Mexico (Cervantes-Diaz et al. 2004) and, more recently in plants showing a little leaf disease in India (Singh et al. 2011).

7.5 Bleeding Heart (*Dicentra spectabilis* L.)

The ornamental species *D. spectabilis* (bleeding heart, ladies locket) (Fumariaceae) produces fleshy tuberous roots, but it is more frequently listed as a perennial than bulbous crop. It is propagated by cuttings or by seeds. Symptoms of shoot proliferation, along with small reddened or chlorotic leaves, were reported in Poland and were associated with 16SrI-B or 16SrI-A phytoplasmas (Kaminska et al. 2004).

7.6 *Brachyscome* spp.

Madhupriya et al. (2013a) reported leaf yellows and witches’ broom symptoms on *Brachyscome* spp. (Asteraceae) in India. Sequence analysis of amplified sequences revealed 99% identity with the 16S rRNA gene of strains belonging to ‘*Ca.* P. asteris’ (16SrI group).

7.7 Burning Bush (*Dictamnus albus* L.)

Valiunas et al. (2007) identified phytoplasma symptoms represented by twisting and recumbent growth of stems, stunting, phyllody, leaf yellowing, and leaf crinkle in this ornamental shrub in Lithuania and found their association with 16SrIII-F phytoplasmas.

7.8 Calendula (*Calendula officinalis* L.)

Phytoplasmas belonging to subgroup 16SrII-E were detected in wild calendula (Asteraceae) showing malformed flowers in Sardinia, Italy (Tolu et al. 2006). Phytoplasma-infected *C. officinalis* was reported in India (Khurana et al. 1981; Rani et al. 2014) and in Iran (Esmailzadeh Hosseini et al. 2016); different phytoplasmas were identified in the various countries (Table 7.1).

7.9 Candytuft (*Iberis sempervirens* L.)

Iberis sempervirens (Brassicaceae) is one of the few flowering plants available in Europe for the market in wintertime. In winter/spring 2013, the two varieties Tahoe and Fish Back, produced by seed in Ligurian Riviera (Italy), showed symptoms of yellowing, stunting, and witches' broom (Fig. 7.2). Detection of 16SrX group phytoplasmas was obtained after nested PCR/RFLP analyses. Sequencing of the 16S rDNA gene confirmed that the phytoplasma infecting *I. sempervirens* showed 99% identity to '*Ca.* P. mali'. Moreover, RFLP analyses indicated the presence of aster yellows phytoplasmas (subgroups 16SrI-B and 16SrI-A) in mixed infection with 16SrX phytoplasmas in the Fish Back variety. This has been one of the few detections of phytoplasmas related to the 16SrX-A group from a herbaceous species worldwide (Contaldo et al. 2015a).

7.10 Chinese Aster (*Callistephus chinensis* L.)

The first reports of phytoplasmas in Chinese aster (Asteraceae) were by electron microscopy (Hemmati and Mc Lean 1980) in Canada and in some cases also by serology (Sinha and Benhamou 1983). Wang and Hiruki (2005) reported detection and estimation of genetic divergence of phytoplasmas associated with the Chinese aster yellows with the help of heteroduplex mobility assay (HMA). Flower virescence symptoms were recently observed also in Yezin, Myanmar. The symptoms usually start with the emergence of new yellow leaves during the vegetative growth

Fig. 7.2 *Iberis sempervirens* showing symptoms of yellowing, stunting, and witches' broom

stage, followed by the leaf petiole turning upright with the clustering of leaves; then, the affected plants stop growing and remain stunted. At the later stage, some flowers show green petals instead of normal color. The phytoplasma was identified as belonging to subgroup 16SrII-A (Win et al. 2011). Further reports of phytoplasma presence are from Lithuania (Navalinskiene et al. 2005).

7.11 Chinese Hibiscus (*Hibiscus rosa-sinensis* L.)

In Brazil, witches' broom disease was first reported in São Paulo State in plants of *H. rosa-sinensis* (Malvaceae); leaf yellowing and malformation as well as short internodes were also present in symptomatic plants (Vicente et al. 1974). Later, the disease was observed, in the State of Rio de Janeiro, in plants of the same species; they displayed similar symptoms and premature dropping of flowers (Kitajima et al. 1984; Kitajima 1994). The phytoplasma associated with hibiscus witches' broom disease in Brazil is reported as '*Ca.* P. brasiliense' belonging to subgroup 16SrXV-A that was in some cases associated with "stolbur" phytoplasmas (16SrXII-A)

(Montano et al. 2001, 2011). In Australia, an unidentified phytoplasma has been reported to be associated with a witches' broom disease of *H. heterophyllus*, an Australian native species that is also grown commercially (Hiruki 1987). Chaturvedi et al. (2010b) reported in India a little leaf disease of *H. rosa-sinensis* associated with 16SrI group of phytoplasmas, and Khasa et al. (2016) reported association with the same disease of clover proliferation (16SrVI) group phytoplasmas.

7.12 *Chrysanthemum* spp.

Phytoplasma diseases mainly represented by virescence (Fig. 7.3) in *Chrysanthemum* spp. (sin. *Dendranthema grandiflorum* L.) (Asteraceae) were firstly found in Sweden, Belgium, Brazil, and Japan (Pettersson and Tomenius 1979; Verhoyen et al. 1979; Kitajima and Costa 1979, Shiomi and Sugiura 1983). Conti et al. (1988) described typical yellows disease in *Chrysanthemum*, and this species was also used as a model plant to study several phytoplasma features in Italy. Galetto et al. (2007) produced polyclonal and monoclonal antibodies against membrane proteins of 'Ca. P. asteris'; Bosco et al. (2007) reported the multiplication rate of the same phytoplasma in three leafhopper vector species (*Euscelis incisus*, *Euscelidius variegatus*, and *Macrosteles quadripunctulatus*); and D'Amelio et al. (2007) described effects of elicitors of plant resistance on *Chrysanthemum* yellows-infected plants. In Serbia, 16SrXII-A phytoplasmas (Duduk et al. 2006) and in South Korea, aster yellows (16SrI) (Bongnam et al. 2007) were reported in *Chrysanthemum*, but in the latter case, two different symptoms were also described such as witches' broom and yellows, and the phytoplasmas 16SrI and 16SrXII-A were reported as being associated with these symptoms, respectively (Chung and Kim 2005). The identification of 16SrII group phytoplasmas has been reported in *Chrysanthemum* in Japan (Naito et al. 2007). Min et al. (2009) reported a 16SrI-B phytoplasma associated with flattened stems, shortening of internodes, yellowing of leaf margins, root death, and dwarfing of plants in China. They also indicated a significant loss in quality of

Fig. 7.3 Strong virescence in two *Chrysanthemum* plants due to phytoplasma presence

flowers due to phytoplasmas; in some affected plants, there is no flower at all. Bayat et al. (2013) reported the association of a '*Ca.* P. phoenicium'-related phytoplasma strain with a *Chrysanthemum* disease in Iran. Raj et al. (2007a) reported association of '*Ca.* P. asteris'-related phytoplasmas (16SrI) with little leaf disease on *Chrysanthemum morifolium*. Aido (2017) recorded symptoms of little leaf, yellowing, chlorosis, phyllody, witches' broom, and stunting in *Chrysanthemum* plants during 2015–2017 and verified the presence of four groups and five subgroups of phytoplasmas: 16SrI-B, 16SrII-A, 16SrII-D, 16SrVI-D, and 16SrXIV-A in India on the basis of RFLP analysis of 16S rDNA amplified sequences.

7.13 Cock's Comb (*Celosia argentea* L., sin. *C. cristata* L.)

Celosia argentea (Amaranthaceae) is grown in Western countries as an ornamental plant, either as potted or for cut flowers. Yellows diseases are common in Israel, and phytoplasma presence was detected in some of diseased plants. Commercial fields of *Celosia plumosa* and *C. cristata* exhibited yellows symptoms and even total crop failure where 16SrI and16SrIII phytoplasmas were detected (Tanne et al. 2000). Phytoplasmas belonging to 16SrI-M were identified on *C. argentea* from Lithuania (Samuitiene and Navalinskiene 2006), '*Ca.* P. asteris' (16SrI-B) and '*Ca.* P. australasia' (16SrII-D) were also detected in samples from India (Madhupriya et al. 2017) and Iran (Aldaghi and Bertaccini 2015), while clover proliferation phytoplasmas (16SrVI group) were identified in Iran (Babaie et al. 2007).

7.14 Cycads

Abnormal yellowing symptoms were observed in India on two species, *Cycas revoluta* (Cycadaceae) and *Zamia furfuracea* (Zamiaceae), of the order Cycadales both associated with the presence of 16SrII phytoplasmas (Kumar et al. 2012a).

7.15 Cyclamen (*Cyclamen persicum* Mill.)

Phytoplasmas were detected for the first time on cyclamen hybrids (Primulaceae) in Italy (Bertaccini 1990). During the first year, symptoms consisted of phyllody and virescence; during the second year, the plants stopped flower production, and the new leaves were dwarfed, very similar to those of wild cyclamens. Some years later, phytoplasmas associated with a cyclamen disease in Germany were found to be

Fig. 7.4 Symptoms related to phytoplasma presence in cyclamen pot and flowers. Little leaf and typical green petals are present together with flower malformations and virescence

identical, based on RFLP patterns, to the American aster yellows (AAY) strain, belonging to the 16SrI-B subgroup (Seemüller et al. 1998). In 2000, in Italy, phytoplasmas belonging to aster yellows 16SrI-B and I-C subgroups were found in five cyclamen plants with virescence and yellow stunted leaves and in one plant showing phyllody and rolled and thickened leaves. Two cyclamens, representing the two syndromes, were chosen as source plants for transmission trials in which three leafhopper species, known as vectors of 16SrI-B and 16SrI-C phytoplasmas, were used to inoculate healthy cyclamen and periwinkle plants. The extremely low level of transmission obtained, to both cyclamen and periwinkle, suggested that cyclamen is an unsuitable species for phytoplasma acquisition and can be regarded as a dead-end host plant for these phytoplasmas (Alma et al. 2000). Recently, cyclamen plants showing phytoplasma-associated symptoms were observed in a farm specialized in potted production in Liguria region (Italy). The symptomatology was represented mainly by strong modification of flowers enclosing virescence and phyllody; in several leaves stunting and rosetting were also present (Fig. 7.4). RFLP analyses allowed to identify phytoplasmas as belonging to 16SrI-B subgroup and further classified as rpI-B, SecYI-B, and GroElIII groups (Satta et al. 2013).

7.16 Desert Rose (*Adenium obesum* L.)

Desert rose (Apocynaceae) is an exotic ornamental plant from warm climates, grown for its attractive fleshy stem, leaves, and bright colorful flowers. It is a succulent plant originating from East Africa, commonly cultivated in humid, tropical areas such as India, the Philippines, and Thailand. Raj et al. (2007a) reported the association of '*Ca.* P. asteris' (group 16SrI) with a little leaf disease in India, while Win et al. (2012) indicated desert rose as a new host for '*Ca.* P. aurantifolia' (group 16SrII) in Myanmar.

7.17 Four O'Clock Flower (*Mirabilis jalapa* L.)

The four o'clock flower (Nyctaginaceae), a native of tropical South America, has been naturalized as an ornamental garden plant in many parts of the world. Plants with small yellow leaves and distorted flowers were observed in home gardens in the north of Israel (Sobolev et al. 2007). Sequence analysis of the PCR product from symptomatic *M. jalapa* clustered within those of phytoplasmas in group 16SrII. The same phytoplasma group was detected also in India (Kumar et al. 2012b) in stunted plants showing crowding of younger leaves, shortening of internodes, and small-sized leaves and flowers.

7.18 Garden Cosmos (*Cosmos bipinnatus* Cav.)

In 2003 16SrI-B phytoplasmas were detected in garden cosmos (Asteraceae) plants showing different symptoms in Mexico. It was suggested that a single type of phytoplasma was associated with the symptoms of phyllody, apical dwarfing, and yellowing (Rojas-Martínez et al. 2003a).

7.19 Garden Croton (*Codiaeum variegatum* L.)

Croton (Euphorbiaceae) with its amazing colors and leathery leaves has been popular in tropical gardens for centuries. Reports of phytoplasma diseases include 16SrII group in Uganda (Arocha et al. 2008) and 16SrI in Colombia (Perilla-Henao et al. 2012). Identification of subgroups 16SrI-B and 16SrVI-C in samples from India was also recently reported (Tiwari et al. 2014).

7.20 *Gladiolus* spp.

Aster yellows disease of *Gladiolus* spp. (Iridaceae) has been widely distributed throughout the USA, where it was first described (Magie et al. 1952). Originally, the disease, referred to as "grassy top," "hairy roots," or "green fin" (Albouy 1966), was reported to be widespread in Belgium, France (Cousin et al. 1968), Italy, Rumania, and Portugal (Bertaccini and Marani 1980; Bellardi et al. 1985; Bertaccini et al. 1990b, 1992b; Ploaie et al. 1981; Louro et al. 1996). Phytoplasmas infecting gladiolus were mainly identified in virescent flowers (Fig. 7.5) on the basis of histopathology, PCR assays, and dot hybridization, which were determined to be 16SrI-B and 16SrI-A phytoplasmas (Bertaccini et al. 1990b, 1992b; Rudzinska-Langwald

Fig. 7.5 Top, a gladiolus flower spike cv. Rose Supréme showing virescence due to aster yellows phytoplasmas compared to a normal flower spike below

and Kaminska 2003). In India Raj et al. (2009) identified '*Ca.* P. asteris' associated with malformation of floral spikes.

7.21 Hydrangea (*Hydrangea macrophylla* Thunb.)

The genus *Hydrangea* (Saxifragaceae) is composed of several deciduous shrubs; this genus encompasses almost 25 species; of these, *H. macrophylla*, native to Japan and China, is the most popular cultivated species, with over 600 recognized cultivars and hybrids, grown in both temperate and subtropical climates. Phytoplasma diseases may have a significant impact on the appearance, health, and market value of hydrangea. Cousin and Sharma (1986) and Pisi et al. (1990) detected phytoplasmas in TEM sections. Phytoplasmas belonging to subgroups 16SrI-A and 16SrI-B have been found infecting hydrangea worldwide, especially in Canada, Japan, and Europe (Bertaccini et al. 1992a; Hiruki et al. 1994; Marzachì et al. 1999; Alioto et al. 2000; Duduk et al. 2013). In Japan, the disease was called "Japanese hydrangea phyllody" (JHP) and identified phytoplasmas belong to '*Ca.* P. japonicum' (Sawayanagi et al. 1999). In addition, 16SrXII-A "stolbur" phytoplasmas were reported in Bulgaria more than 20 years ago in mixed infection with aster yellows (Bertaccini et al. 1995). In 2011 and 2012, an epidemiological survey was carried out in Liguria and Lazio regions (Italy) (Bertaccini et al. 2015). Hydrangea plants showing stunting, flower virescence and phyllody, yellowing, necrosis, and redness of the leaf edge were collected in commercial greenhouses and plants with flower virescence and red edges of leaves (Fig. 7.6) infected with phytoplasmas in the 16SrI-B subgroup. Further, RFLP analysis of the *GroEl* gene with *Tru1*I and *Alu*I allowed it to be assigned to the GroEl subgroup III. In Bolsena city (Lazio region), plants showing growth reduction, flower virescence, and phyllody, but with

Fig. 7.6 From left: hydrangea plants with flower virescence and red edges of leaves infected by 16SrI-B phytoplasmas; hydrangea plants, showing growth reduction, flower virescence, and phyllody infected by 16SrXII-A "stolbur"

asymptomatic leaves (Fig. 7.6), were infected by 16SrXII-A, "stolbur" phytoplasmas that were further characterized by their *tuf* gene. In these diseased hydrangea plants '*Ca.* P. asteris'-related phytoplasmas were identified in *L. striatellus*, while "stolbur" (16SrXII-A) phytoplasmas were present in *Anaceratogallia* sp. More recently, in Japan Kesumawati et al. (2006) studied the interaction between phytoplasma concentration and green-flowering stability in *H. macrophylla* and phylogenetic analyses based on multigene sequences, indicating that symptomatic hydrangea plants were associated with phytoplasmas belonging to '*Ca.* P. asteris' (Takinami et al. 2013).

7.22 Ice Plant (*Carpobrotus edulis* L.)

Shukla et al. (2014) reported extensive yellowing, little leaves, and reduced flower size in *C. edulis* (Aizoaceae) at Gorakhpur gardens, Eastern Uttar Pradesh, India. The associated phytoplasma was identified as belonging to the 16SrIX-C subgroup.

7.23 *Jasminum sambac* L.

Jasmine (Oleaceae) is a popular ornamental plant and is traditionally used for flowers and tea; it is cultivated commercially also for the perfume industry and herbal medicine. Group 16SrII phytoplasmas in Arabian jasmine were detected in Oman (Al-Zadjali et al. 2007), group 16SrI-B in Italy (Marzachì et al. 1999), and group 16SrXI in India (Madhupriya et al. 2015) associated with little leaf, yellows, and witches' broom symptoms.

Fig. 7.7 Lachenalia plants showing growth reduction and severe leaf and flower malformations

7.24 Lachenalia (*Lachenalia aloides* L.)

Lachenalia (Asparagaceae) is an elegant bulbous ornamental plant endemic to southern Africa. In 2016, several lachenalia pot plants at a flower bulbous grower in the Liguria region (Italy) were showing phytoplasma-like symptoms: growth reduction, severe flower malformation and virescence, yellow stripes, and variegation on the rolled leaves; in only one plant, some of the smaller flowers were normal in color (yellow and purple) (Fig. 7.7). Nested PCR and RFLP analyses using restriction enzyme *Tru1*I classified the phytoplasmas as belonging to ribosomal group 16SrI-B (Bellardi et al. 2017).

7.25 Lilac (*Syringa* spp.)

Hibben et al. (1986) detected phytoplasmas in the phloem sieve tubes of leaves of *Syringa vulgaris* (Oleaceae) plants showing lilac witches' broom by Dienes' stain. Electron microscopy observations and susceptibility of lilac to this disease were reported in the USA, and the phytoplasma detected was classified in subgroup 16SrVII-A (Hibben et al. 1986; Hibben and Franzen 1989, Griffiths et al. 1994, 1999).

7.26 Lily (*Lilium* spp.)

The earliest description of aster yellows-type diseases in lilies was that of Ogilvic and Guterman in 1929 in the USA. They described a disease on *Lilium longiflorum* cultivars characterized by severe leaf chlorosis and malformation, stunted growth, and flower distortion. In 1954, Brierley and Smith described symptoms of lily rosette in *L. longiflorum* cultivars Croft and Georgia. The affected plants showed stunting and rosette-like symptoms. Bertaccini and Marani (1982) described a flower and leaf malformation and discoloration in the lily hybrid Pink Perfection associated with multiple infections of lily mottle and lily symptomless viruses and the presence of phytoplasmas in Italy. Recently, PCR amplification of 16S rDNA and RFLP analysis indicated that stunting and flower bud deficiency symptoms in hybrid Casablanca were associated with infection by aster yellows phytoplasma and viruses (Kaminska et al. 1998; Kaminska and Korbin 1999; Bertaccini et al. 2005). In 1997–2000 phytoplasma infection was reported in plants of several lily cultivars with different symptoms (Poncarova-Vorackova et al. 1998; Kaminska and Korbin 2000; Bertaccini et al. 2002) in the Czech Republic and Poland. Moreover, in Poland, Kaminska and Śliwa (2008a) reported '*Ca.* P. mali' in oriental lilies. The presence of '*Ca.* P. solani' association with lily stem flattening disease was reported by Chung and Jeong (2003) in South Korea, while Cortes-Martinez et al. (2007) reported a 16SrI phytoplasma associated with a zigzag line pattern in leaves of *Lilium* sp. in Mexico.

7.27 Lupine (*Lupinus polyphyllus* Ltd.)

Ornamental lupine (Fabaceae) is an elegant herbaceous plant native to Northern America, used as pot plants, in home gardens, and for cut flower production. In May 2012, phytoplasma-like symptoms were observed on ornamental lupine pot plants, obtained by seed, at an ornamental grower in Ligurian Riviera (Italy) (Bellardi et al. 2013). Some plants at the blooming stage showed shortened internodes, the floral stems bent like an "S" shape, and younger leaves were smaller and rolled (Fig. 7.8). Nested PCR and RFLP analyses of the 16S rDNA from symptomatic leaves and flowers identified "stolbur" phytoplasmas (16SrXII-A) (Contaldo et al. 2013).

7.28 *Magnolia* spp.

The genus *Magnolia* spp. (Magnoliaceae) comprises about 80 species of trees and shrubs that are naturally distributed throughout eastern North America and Southeastern Asia. Magnolias are relatively free of pests and diseases; however, a severe phytoplasma disease designated as *Magnolia* stunt and yellows was observed

Fig. 7.8 Ornamental lupine flower stems: on the left, a normal one; on the right, plant infected by "stolbur" phytoplasmas

in plants growing in some gardens and nurseries and in imported plants in Poland. The identified phytoplasma was aster yellows (16SrI) (Kaminska et al. 2001b).

7.29 Marigold (*Tagetes erecta* L.)

Stunting and lack of flower production (Fig. 7.9) are the main symptoms exhibited by *Tagetes* spp. (Asteraceae) infected by phytoplasmas. Raj et al. (2011) reported little leaf and witches' broom symptoms on marigold from India. In Mexico, marigold phyllody was reported by Zavaleta-Mejia et al. (1993), and the phytoplasma which induces marigold phyllody belonged to the aster yellows group (16SrI-B) (Rojas-Martínez et al. 2003b). Pot marigold phyllody was observed in a botanical garden in Yazd Province of Iran (Esmailzadeh Hosseini et al. 2011). In Italy, witches' broom disease is frequent in small gardens.

7.30 Opuntia and Cactus Species

Ornamental cacti were reported to show several symptoms associated with phytoplasma presence. Some of these were ornamentals such as *Opuntia monacantha* Willd. (Cactaceae) in Lebanon (Choueiri et al. 2005), *Opuntia* sp., and *Zygocactus*

Fig. 7.9 Phytoplasma-infected marigold plants near healthy plants

truncatus Haw. in China (Cai et al. 2007, 2008). Phytoplasmas were reported to be associated with ornamental cacti such as *Echinopsis subdenudata* and *Opuntia* sp. also in Mexico (Hernández-Gutiérrez 1993; Leyva-Lopez et al. 1999; Avina-Padilla et al. 2009). Tessitori et al. (2006) and Granata et al. (2006) for the first time reported phytoplasmas associated with abnormal proliferation of cladodes in *Opuntia ficus-indica* Mill. in Italy. Bertaccini et al. (2007) developed a method for phytoplasma detection in *O. ficus-indica* in California (USA).

7.31 Pansy (*Viola tricolor* L.)

Leaf yellows and little leaf symptoms observed on *Viola tricolor* (Violaceae) plants at Indian Agricultural Research Institute campus, New Delhi, in 2012–2013 are associated with the presence of '*Ca.* P. asteris' (Shukla et al. 2015).

7.32 Paris Daisy [*Argyranthemum frutescens* (L.) Lch. Bip.]

Argyranthemum frutescens, known as Paris daisy, marguerite, or marguerite daisy (Asteraceae), is a perennial plant known for its lovely flowers. Phytoplasma infections in *A. frutescens* plants have already been reported and associated with phytoplasmas belonging to the aster yellows (16SrI) and elm yellows (16SrV) ribosomal groups (Bertaccini et al. 1990a, 1992a; Boarino et al. 2002). Ferretti et al. (2015) reported the association of 16SrIX-C phytoplasma group with plants showing general yellowing and stunting, little leaf, and/or abnormal proliferation of axillary shoots resulting in the appearance of witches' broom and reduced flower size.

7.33 Periwinkle [*Catharanthus roseus* (L.) G. Don.]

Periwinkle (Apocynaceae) is a perennial commonly used as an experimental host to maintain phytoplasmas since it is able to harbor the majority of known phytoplasmas (Shaw et al. 1993). Detection of phytoplasmas in periwinkle has been reported all around the world (Ploaie et al. 1977; Okuda 1977; Shishlova and Andreeva 1978; Mc Coy and Thomas 1980; Rao et al. 1983; Chen et al. 1984;Clark and Davies 1984; Grimaldi and Grasso 1988; Khurana et al. 1981; Chaturvedi et al. 2009b; Kumar and Byadgi 2012; Parrella et al. 2014; Madupriya et al. 2016). Using periwinkle as an experimental host has enabled the following research: (1) Chen and Hiruki (1978) reported the preservation of membranes of tubular bodies associated with phytoplasmas by tannic acid in *C. roseus* plants infected with aster yellows, (2) Carling and Millikan (1978) observed banded filaments associated with aster yellows in *C. roseus* in the USA, (3) Cousin and Abadie (1982) reported the action of phytoplasmas on the anther of *C. roseus* with the help of light and electron microscopy studies, (4) Schmitt et al. (1983) reported pleomorphism of phytoplasmas in periwinkle, (5) Moreno et al. (1985) described and compared several yellows diseases on *C. roseus* in Spain, (6) Rocha et al. (1986) detected phytoplasmas in *C. roseus* by indirect immunofluorescence microscopy, (7) Schmitt et al. (1987) observed freeze-fracture SEM of phytoplasmas in the phloem of *Catharanthus* sp., (8) a polyclonal antiserum was produced against a phytoplasma strain in periwinkle (Bellardi et al. 1992), (9) Davis et al. (1988) detected phytoplasmas in *C. roseus* using cloned nucleic acid hybridization probes, (10) Deng and Hiruki (1990) reported molecular cloning and detection of DNA of clover proliferation phytoplasmas in *C. roseus*, and (11) Davis et al. (1990) reported molecular cloning and detection of chromosomal and extrachromosomal DNA associated with little leaf disease in *C. roseus* in the USA.

The major aster yellows phytoplasma subgroups (16SrI-A, 16SrI-B, and 16SrI-C) have a wide host range and may also occur together in the same host. In periwinkle, subgroups 16SrI-A and 16SrI-B induce a wide variety of symptoms such as virescence, phyllody, small and light pink petals, flower malformations, shortening of internodes, elongation of internodes, plant yellowing, and small and deformed leaves. Periwinkles are known to be susceptible to the AY (16SrI) group phytoplasma in several countries, such as Malaysia (Khew et al. 1991) and Argentina (Torres et al. 2004). Omar et al. (2008) observed little leaves, shortened internodes, virescence, and witches' broom symptoms associated with infected periwinkle plants growing in Egypt, and the Egyptian phytoplasma virescence (EPV) detected in diseased periwinkle was identified as AY.

7.34 Persian Buttercup (*Ranunculus asiaticus* L.)

Phytoplasmas infecting Persian buttercup (Ranunculaceae) were first reported in France in 1968 (Devergne and Lovisolo 1969) and 20 years later in Italy (Bertaccini et al. 1988). The presence in diseased samples of a '*Ca.* P. asteris'-related strain, belonging to the 16SrI-B subgroup, was demonstrated by PCR/RFLP and phylogenetic analysis in Campania (southern Italy) (Parrella et al. 2008).

7.35 Petunia (*Petunia hybrida*)

Petunia (Solanaceae) is an economically important ornamental widely grown worldwide. In its hybrids, a phytoplasma disease was first reported in 1964 from plants showing stunting or yellowing (Doi et al. 1967). Natural occurrence of different groups of phytoplasmas was reported from several countries: a 16SrIII group was associated with a little leaf in Australia; 16SrI group was associated with flat stem, yellows, and witches' broom in Korea, Iran, and India and a 16SrXII group in Iran. Later, 16SrI phytoplasmas were associated with petunia flat stem in both China and South Korea (Chung and Hun 2008). Chung et al. (2013) reported "stolbur" phytoplasmas (16SrXII-A) in commercial petunias showing an unusual multiple plantlet sprouting from the lateral buds in a greenhouse in Gwacheon, Gyeonggi Province, China. Faghihi et al. (2014) reported the association of 16SrII phytoplasmas with plants showing witches' broom, yellowing, little leaf, phyllody, and virescence symptom in Sistan and Baluchestan Province of Iran. Leaf yellows symptoms were recorded on *Petunia* species associated with 16SrI phytoplasmas (Singh et al. 2011) and flattened stem and witches' broom symptoms (Madhupriya et al. 2014) in India.

7.36 *Phlox* spp.

Zajak (1979) observed by transmission electron microscopy phytoplasmas of 150–1200 nm diameter in sieve tubes of *Phlox paniculata* L. (Polemoniaceae) with flower virescence and Misra et al. (1985) detected them in phloem sieve tubes of *P. drummondii* Hook. plants in Rajasthan, India. Recently Navalinskiene and Samuitiene (2004) reported the same species infected by phytoplasmas belonging to subgroup 16SrI-M in Lithuania. Madhupriya et al. (2013b) reported extensive yellowing, stunting, proliferation of shoots, little leaves, and reduced size of flowers like symptoms on *P. drummondii* at New Delhi, India. Sequence analysis confirms 99% sequence identity with the 16S rRNA gene of strains belonging to the '*Ca.* P. phoenicium' (16SrIX group).

7.37 Purple Coneflower (*Echinacea* spp.)

Purple coneflower (Asteraceae) is native to North America. Plants showing general leaf yellowing, reddening, and stunting were described in Alberta (Canada) where phytoplasma-infected plants sometimes have extremely small, numerous, branched, axillary shoots coming from the stem nodes, giving them a bunchy or witches' broom appearance (Hwang et al. 1997). In the purple coneflower, phytoplasmas belonging to the aster yellows group have been identified (Stanosz et al. 1997; Khadhair et al. 1997; Chang et al. 2000; Lee et al. 2008); in particular, in the USA the subgroups 16SrI-A and 16SrI-B were identified. Radisek et al. (2008) also reported a 16SrI-C phytoplasma infecting purple coneflower in Slovenia, while Bertaccini et al. (2009) reported the association of 16SrIX-C and 16SrI-B phytoplasmas in *E. purpurea* (L.) Moench. plants showing yellowing, phyllody, and virescence symptoms (Fig. 7.10). In Serbia, *E. purpurea* and *E. angustifolia* L. were observed to show phytoplasma symptoms. The symptoms on *E. purpurea* were yellowing in the early stages of disease development; foliage reddening, plant stunting, and proliferation of axillary shoots appear as the disease progresses, and infected plants showed bunchy or witches' broom appearance. Symptoms on *E. angustifolia* were stunting, shortened internodes, and purplish-reddening leaves and stalks. Flowers on such plants were found smaller and did not bear seeds. Molecular identification confirmed the presence of 16SrXII-A ("stolbur") phytoplasmas in both species investigated (Pavlovic et al. 2010). Purple coneflower plants showing leaf reddening and flower abnormalities were observed in South Bohemia (Czech Republic) where phytoplasmas were observed by transmission electron microscopy and identified as belonging to 16SrI-C and 16SrIII-B subgroup. The identity of the latter was also confirmed after sequence analyses of the 16S–23S ribosomal operon, ribosomal protein L15, and protein translocase genes (Franova et al. 2009, 2013).

Fig. 7.10 Purple coneflower showing strong virescence and malformation symptoms due to the presence of mixed phytoplasma infection in Italy

7.38 Queen Anne's Lace (*Daucus carota* L.) and Poker Statice [*Psylliostachys suworowii* (Regel) Roshk]

Queen Anne's lace (Apiaceae) and poker statice (Poaceae) are widely cultivated ornamentals. They were found with a yellows-type disease with typical phytoplasma symptoms in an experimental farm near Brooks, Alberta, Canada, in 1996. Further study provided the first record of 16SrI phytoplasmas in Queen Anne's lace and poker statice (Chang et al. 2004).

7.39 Rose (*Rosa* spp.)

Rose (Rosaceae) is the most important and popular garden plant in the world and the most important commercial cut flower cultivated in glasshouses. Several virus-like diseases of uncertain etiology have been reported in rose throughout the world. Rose wilt was first recorded in Australia in 1908, but the symptoms were later described more fully by Grieve (1931) and Fry and Hammett (1971) in New Zealand. In the United Kingdom, Hollings (1961) recorded the occurrence of rose bud proliferation, rose wilt, and rose dieback, also called rose winter dieback (Thomas 1979). Some rose degeneration symptoms have been reported from Bulgaria (Hristova 1974), France (Devergne and Coujon 1975), the Netherlands (Bos and Perqin 1975), and Poland (Kaminska et al. 2001a, 2003, 2006; Kaminska and Sliwa 2004). Rose rosette disease, also referred as rose witches' broom, was first reported in Manitoba on wild rose species by Connors in 1941 and subsequently in other parts of Canada and the USA (Epstein and Hill 1995). The disease is endemic in much of the south-east, south-central, and north-central USA (Hindal et al. 1988; Tipping and Sindermann 2000). Similar symptoms known as rose dieback or rose wilt were recorded in garden roses by Cheo (1970) and Gumpf and Weathers (1974). In 1976, rose leaf curl (Slack et al. 1976a), which resembles rose wilt disease and rose spring dwarf, was more fully described in the USA (Slack et al. 1976b). Research in various parts of the world demonstrated the presence of an aster yellows (16SrI) phytoplasma associated with phyllody symptoms in Poland (Kaminska et al. 2003), India (Fig. 7.11) (Chaturvedi et al. 2009a), and China (Gao et al. 2008). Madhupriya et al. (2017) reported leaf chlorosis, phyllody, virescence, and little leaf symptoms in various rose cultivars associated with subgroups 16SrI-B and 16Sr II-D in India.

Fig. 7.11 Yellows and pale flower in rose affected by aster yellows phytoplasmas in India

7.40 Rose Balsam (*Impatiens balsamina* L.)

Rose balsam (Balsaminaceae) is an ornamental species cultivated in China, where the red flower is often used as nail polish in rural regions. Phytoplasmas of the 16SrI group were reported in plants showing phyllody in China (Li et al. 2011). More recently (Li et al. 2014), subgroup 16SrV-B phytoplasmas were detected in plants with wrinkled leaves, phyllody, deformed and shortened internodes, stunting, and no seed production.

7.41 Moss Rose (*Portulaca grandiflora* L.)

Ajaykumar et al. (2007) and Samad et al. (2008) reported in India a little leaf disease of *P. grandiflora* (Portulacaceae) known also as eleven o'clock, Mexican rose, moss rose, Vietnam rose, sun rose, and rockrose. The symptomatic plants displayed bud proliferation, downward curling, and diminished size of leaves, followed by overall stunted growth and general yellowing; some plants also show a witches' broom appearance and 16SrVI phytoplasmas were identified.

7.42 Soapwort (*Saponaria officinalis* L.)

S. officinalis (Caryophyllaceae) is a common perennial plant from the carnation family. This plant has many common names, including common soapwort, bouncing-bet, crow soap, wild sweet William, and soapweed. Khasa et al. (2016) observed witches' broom symptom associated with 16SrVI group phytoplasmas in India.

7.43 Scotch Broom (*Cytisus scoparius* L. sin. *Sarothamnus scoparius* L.)

A witches' broom and stunting were observed in a group of shrubs of *Cytisus scoparius*, better known as common broom or scotch broom growing in Berlin-Dahlem Botanical Garden and Botanical Museum in Berlin (Germany). This is a perennial shrub native to western and central Europe, but it is considered an invasive plant in North America and New Zealand. Symptomatic *C. scoparius* were analyzed by nested PCR/RFLP, and '*Ca.* P. spartii' in mixed infection with '*Ca.* P. asteris' was detected. In some samples of *C. scoparius*, "stolbur" phytoplasmas were also identified (Contaldo et al. 2015b).

7.44 Siamese Rough Bush (*Streblus asper* Lour)

Streblus asper (Moraceae) is an important medicinal and ornamental plant distributed in tropical countries such as India. Maurya et al. (2014) recorded association of '*Ca.* P. asteris' (16SrI) with *S. asper* plants showing chlorosis and little leaf symptoms growing in different gardens and nurseries of Gorakhpur, India.

7.45 Spanish Broom (*Spartium junceum* L.)

Spanish broom (Fabaceae) is a deciduous shrub with dark green, round stems and alternate leaves; inflorescences are terminal clusters of several bright yellow somewhat fragrant flowers. This ornamental shrub grows naturally especially in southern Italy where it is affected by spartium witches' broom (SpaWB) disease, characterized by proliferation of axillary buds and stem fasciation. Two phytoplasmas were associated with this disease: '*Ca.* P. spartii' a member of the apple proliferation phylogenetic group (16SrX-D), and a phytoplasma belonging to elm yellows group (16SrV-C) (Marcone et al. 1996, 1997a, 2004; Torres et al. 2002; Mancini et al. 2010). Both phytoplasmas were reported associated with SpaWB in Italy, while

Fig. 7.12 Typical SpaWB symptoms in a plant growing in the city of Ercolano (Campania region, Italy)

only '*Ca*. P. spartii' was reported in Spain. More recently typical SpaWB symptoms were observed in a plant up to 2 m tall growing in the city of Ercolano (Campania region, Italy) (Fig. 7.12). Nested PCR/RFLP analyses showed the presence of '*Ca.* P. spartii' in mixed infection with '*Ca.* P. asteris' (Contaldo et al. 2015b).

7.46 *Spiraea* spp.

Spireas (*Spiraea* spp.) (Rosaceae) are woody perennial ornamentals that are widely grown throughout Minnesota and in other US states due to their cold hardiness and adaptability to a variety of low-maintenance landscape settings. Phytoplasma-infected plants were recorded as showing severe stunting, small leaves, and shoot proliferation (witches' broom). Diverse phytoplasmas were detected in particular in the USA 16SrIII-E phytoplasmas were identified (Griffiths et al. 1994), while 16SrI-B and 16SrV-B subgroups were identified in China (Gao et al. 2007; Li et al. 2010).

7.47 Sunflower (*Helianthus annuus* L.)

Phyllody in sunflower (Asteraceae) was reported in Sudan by Nour (1962), while the first information regarding the presence of phytoplasmas in sunflower was revealed by transmission electron microscopy in southern France (Signoret et al. 1976). Guzman et al. (2014) reported virescence, phyllody, flower malformation, shortened internodes, and abnormal branches on sunflower associated with 16SrIII-J in Argentina. Previous studies have reported the infections caused by phytoplasmas from 16SrII and 16SrVI groups in sunflower in Iran (Tazehkand et al. 2010).

Fig. 7.13 Virescent and malformed flowers of *M. incana* infected by phytoplasmas

7.48 Tenweeks stock (*Matthiola incana* R. Br.)

Tenweeks stock (Brassicaceae) is a common herbaceous ornamental species cultivated in all temperate areas for flower production. In April 2007, a severe disease occurred in Sicily (southern Italy) in a glasshouse cultivation of tenweeks stock cultivar White-Beach. Plants were stunted and rosetted, but the main symptoms, appearing at the flowering stage, were malformation of white flowers and virescence (Fig. 7.13). The incidence of symptomatic plants was about 65%. PCR, RFLP, and sequencing carried out on the 16S rRNA gene, together with phylogenetic comparison of the 16S rRNA, confirmed that the phytoplasmas detected belonged to ribosomal subgroup 16SrII-A ('*Ca.* P. aurantifolia') (Davino et al. 2007).

7.49 Zinnia (*Zinnia elegans* L.)

Rao et al. (2012) reported typical little leaf, chlorosis, witches' broom, yellowing, and phyllody symptoms on *Zinnia elegans* (Asteraceae) at Gorakhpur, India. Sequence analysis revealed 99% sequence identity with the 16S rRNA gene of strains belonging to the '*Ca.* P. asteris' (16SrI) group.

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