Current Status of Phytoplasmas and their Related Diseases in Korea

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Phytoplasmas have been associated with more than 46 plant species in Korea. Several vegetables, ornamentals, fruit trees and other crop species are affected by phytoplasma diseases. Six 16Sr groups of phytoplasmas have been identified and these phytoplasmas are associated with 63 phytoplasma diseases. Aster yellows phytoplasmas are the most prevalent group and has been associated with more than 25 diseases in Korea. Jujube witches’ broom, paulownia witches’ broom and mulberry dwarf diseases cause economic losses to host trees throughout the country. So far, Korean phytoplasmas belong to six species of *Candidatus Phytoplasma*; *Ca. P. asteris*, *Ca. P. pruni*, *Ca. P. trifolii*, *Ca. P. solani* and *Ca. P. castaneae*. The diseases are distributed throughout the country and most of them were observed in Gyeongbuk and Chonbuk provinces. At least four insect vectors; *Cyrtopeltis tenuis*, *Hishiemonus sellatus*, *Macrosteles striifrons* and *Ophiola flavopicta* have been identified for phytoplasma transmission.

**Keywords**: *Candidatus* Phytoplasma’ species, classification, identification

Phytoplasmas, formerly termed mycoplasma-like organisms, were discovered by a group of Japanese scientists in 1967 (Doi et al.). They are minute, wall-less pleomorphic prokaryotes located in sieve elements of the phloem of many plant species. Phytoplasmas severely affect herbaceous and woody plants exhibiting symptoms of virescence/phylloidy, sterility of flowers, witches’ broom, abnormal inter-node elongation, and generalized stunting. Nowadays, phytoplasma diseases are the primary limiting factors for many important crops all over the world (Bertaccini, 2007). In Korea, jujube witches’ broom (JWB) and other diseases such as paulownia witches’ broom (PaWB), mulberry dwarf (MD), and black locust witches’ broom (BlOWB) had been considered as viral diseases but the causal agents for those diseases had not been identified. In 1973, Yi et al. firstly reported the association of mycoplasma-like bodies with witches’ broom affected jujube trees by electron microscope (EM), and Professor So In Yung (1973) identified sweet potato witches’ broom by graft transmission, antibiotic reactions and EM. Then, Kim (1980) reported that witches’ broom of *Rhus javanica* (SuWB) was caused by mycoplasma-like organisms (MLO) using EM. In 1989, Chai and Kim found MLO association with *Ligustrum ovalifolium* witches’ broom by FM observation.

In the 1990s, molecular tools such as PCR/RFLP and nested-PCR of the conserved phytoplasma 16S rRNA gene were developed (Gundersen et al., 1996; Lee et al., 1993; Namba et al., 1993). Total DNAs were extracted from infected samples and phytoplasmas were detected by using the 16S rRNA specific primers and restriction enzyme digestion. In this way, phytoplasmas associated with paulownia, goldenrod and lilac plants were firstly documented by Lee et al. (1996). Then, Han and coworkers worked...
extensively on JWB phytoplasma and proved that it was genetically distinct from sesame phyllody, PaWB, MD, SuWB and chestnut little leaf (CLL) phytoplasmas based on the results of restriction digestion patterns of the 16S rRNA gene primed by SN910601/SN910502 or R16F2/R2 (Han et al., 1997, 2001). In 1998, Han reported the presence of two phytoplasma groups in Korean trees; group I included CLL, PaWB, SuWB and MD, whereas group II included JWB phytoplasma. Chung and coworkers identified chrysanthemum phytoplasmas as aster yellows (AY) phytoplasmas by RFLP comparison to AY phytoplasmas from periwinkle (Chung et al., 2001). Also in 2003, Jung differentiated eight Korean phytoplasmas into three 16S-groups and four subgroups as aster yellows (AY) subgroup in AY 16S-group, chestnut witches’ broom (CnWB) subgroup in CnWB 16S-group, and clover proliferation subgroup and JWB subgroup in Elm yellows (EY) 16S-group based on rrrA sequences of these phytoplasmas. Lee (2004) described 52 phytoplasma diseases in Korea and classified the phytoplasmas into six ‘Candidatus Phytoplasma’ species by analysis of the 16S rRNA gene sequences. Recently, Chung et al. (2011) described seven widespread phytoplasma diseases of floricultural crops in Korea which are associated with aster yellows, stolbur and X-disease phytoplasmas.

So far, 63 phytoplasma diseases have been reported in Korea including the quarantine important phytoplasmas. For simultaneous detection of quarantine phytoplasmas, multiplex PCR assays had been developed firstly by Kim et al. (2011) for easily detection of 10 ‘Ca. Phytoplasma’ species and the phytoplasmas’ association could be recognized by the specific band patterns within a short time. Aster yellows phytoplasmas group is the most prevalent group in Korea and strains generally recognized as members of AY group have not yet been studied for finer differentiation such as subgroups. To reveal the diversity among AY group phytoplasmas, Win et al. studied nine Korean AY phytoplasmas by the 16S rRNA gene sequence and RFLP analysis, and also based on interoperons heterogeneity. From that study, at least two subgroups, 16SrI-B and 16SrI-D, were present. In addition, diversity was demonstrated among 16SrI-B phytoplasmas by the presence of interoperons heterogeneity. Other conserved genes such as ribosomal protein (rp) gene and elongation factor (tuf) gene have been used to differentiate the AY phytoplasmas in that study (Win et al., 2012). Similarly, other AY phytoplasmas should be reclassified to the appropriate subgroups.

**Host plants**

Phytoplasmas are found associated with disorders of several plant species including vegetables, ornamentals, fruit trees

| Table 1. Plant hosts and associated phytoplasma diseases, classification of the associated phytoplasmas as ‘Candidatus Phytoplasma’ species based on molecular analysis, and their geographical occurrence in Korea |
|-----------------------------------------------|
| **Plant host** | **Associated disease** | **‘Ca. Phytoplasma’** | **Phytoplasma group** | **Evidence of identity** | **Accession number** | **Region (province)** | **Selected references** |
| Amaryllidaceae | | | | | | | |
| *Allium cepa* (Onion) | Onion yellow dwarf (OYD) | ‘Ca. P. asteris’ | AY/AY | SA | AB292849 | Gangwon, Gyeongnam | Jung and Kim, 2008 (GB) |
| Anacardiaceae | | | | | | | |
| *Rhus javanica* (Sumac) | Sunac witches’ broom (SuWB) | ‘Ca. P. asteris’ | AY/AY | SA | AB693125 | Chonbuk, Gyeongbuk | Lee et al., 2012 (GB) |
| Apiaceae | | | | | | | |
| *Oenanthe javanica* (Water dropwort) | Water dropwort witches’ broom (WDWB) | ‘Ca. P. asteris’ | AY/AY | RFLP, SA | AB078436 | Chonnam, Gyeongbuk, Gyeongnam | Woo et al., 2001; Jung et al., 2002b |
| *Bupleurum falcatum* (Hare’s ear) | Hare’s ear yellow dwarf (HEYD) | ‘Ca. P. asteris’ | AY/AY | SA | AB693129 | Chonbuk, Gyeongbuk, Gyeongnam | Choi et al., 1985; Lee et al., 2012 (GB) |
| *Cnidium officinale* (Cnidii rhizome) | Cnidium witches’ broom (CdWB) | ‘Ca. P. pruni*’ | WX/WX | EM, FM, SA | NA | Chungbuk, Gyeonggi, Gyeongbuk (Ulleung) | Lee, 2004 |
| *Cryptotaenia japonica* (Japanese hornwort) | Hornwort witches’ broom (HWB) | unclassified | - | Symptom | - | Gyeongbuk (Ulleung) | Lee and Kim, 1994 |
| Araliaceae | | | | | | | |
| *Aralia cordata* (Japanese spikenard) | Udo yellow dwarf (UYD) | ‘Ca. P. pruni*’ | WX/WX | EM, SA | NA | Gyeongbuk (Ulleung) | Lee et al., 2002 |
### Table 1. Continued

| Plant host | Associated disease | ‘Ca. Phytoplasma’ | Phytoplasma group | Evidence of identity | Accession number | Region (province) | Selected references |
|------------|-------------------|------------------|------------------|----------------------|------------------|------------------|-------------------|
| **Asteraceae** | | | | | | | |
| Dendranthema grandiflorum (Chrysanthemum) | Chrysanthemum yellow dwarf (ChYD) | ‘Ca. P. asteris’ | AY | RFLP, SA | AY241706 Gyeonggi | Chung and Kim, 2005 |
| | Chrysanthemum witches’ broom (ChWB) | ‘Ca. P. solani’* | STOL | RFLP, SA | AY169308 Gyeongnam | | |
| Lactuca sativa (Lettuce) | Lettuce proliferation-K | ‘Ca. P. asteris’ | AY | SA | EF489024 Gyeonggi | Chung et al., 2007 |
| Solidago virgaurea (Goldenrod) | Korean goldenrod witches’ broom (GrWB) | ‘Ca. P. pruni’* | WX/WX | FM, EM, RFLP | - | Gyeongbuk (Ulleung) Lee et al., 1996 |
| Aster glehni var. hondoensis | Glehni aster yellow dwarf (GAYD) | ‘Ca. P. pruni’* | WX/WX | FM, SA | NA | Gyeongbuk (Ulleung) Jung and Lee, 2004 |
| Aster ciliosus | Ciliosus aster witches’ broom (CAWB) | ‘Ca. P. pruni’* | WX/WX | FM, SA | NA | Gyeongbuk | Lee, 2004 |
| Liatris spicata (Dense blazing star) | Liatris witches’ broom (LiWB) | unclassified | - | Symptom | - | Gangwon | Hahm et al., 1998 |
| **Buxaceae** | | | | | | | |
| Pachysandra terminalis (Japanese spurge) | Japanese spurge yellows (JSY) | ‘Ca. P. asteris’ | AY/16SrI-B | RFLP, SA | AB551736 Daegu | Back et al., 2010 |
| **Convolvulaceae** | | | | | | | |
| Ipomoea batatas (Sweet potato) | Sweet potato witches’ broom | unclassified | - | EM | - | Chonbuk | So, 1973 |
| **Ericaceae** | | | | | | | |
| Rhododendron sp. (Azalea) | Azalea witches’ broom (AWB) | ‘Ca. P. asteris’ | AY | SA | AB444716 Chonbuk | Han, 2008 (GB) |
| **Euphorbiaceae** | | | | | | | |
| Euphorbia pulcherrima (Poinsettia) | Poinsettia stem flat (PoiSF) | ‘Ca. P. pruni’* | 16SrIII-H | SA | GU461275 Gyeonggi | Chung and Choi, 2010 |
| | Poinsettia branch-inducing (PoiBI) | ‘Ca. P. pruni’* | 16SrIII-H | SA | GU461277 Gyeonggi | | |
| **Fabaceae** | | | | | | | |
| Robinia pseudoacacia (Black locust) | Locust witches’ broom (BLWB) | ‘Ca. P. asteris’ | 16SrI | SA | NA | Gangwon, Chonbuk | Han, 2007 |
| Trifolium repens (Clover) | Clover yellow dwarf (CYD) | unclassified | - | EM | - | Gyeongbuk | Chang, 1981 |
| Lespedeza cyrtobotrya (Leafy lespedeza) | Leafy lespedeza witches’ broom (LLWB) | ‘Ca. P. trifoli’ | - | RFLP, SA | AB279597 Gangwon | Kim and Jung, 2007 |
| **Fagaceae** | | | | | | | |
| Castanea crenata (Japanese chestnut) | Chestnut little leaf (CLL) | ‘Ca. P. asteris’ | AY | RFLP | - | Chonbuk, Chonnam | Han and Cha, 2001 |
| | Chestnut witches’ broom (CnWB) | ‘Ca. P. castaneae’ | CnWB | SA | AB054986 Chonbuk, Gyeongnam | Jung et al., 2002a |
| Quercus acutissima (Sawtooth oak) | Chestnut oak witches’ broom (COWB) | unclassified | - | Symptom | - | Gyeongnam | Lee and Kim, 1994 |
| Castanopsis cuspidata (Japanese chinquapin) | Castanopsis witches’ broom (CasWB) | unclassified | - | EM, FM | - | Gyeongnam, Jeju | Lee et al., unpublished |
| **Gentianaceae** | | | | | | | |
| Gentiana scabra (Japanese gentian) | Gentian witches’ broom (GWB) | unclassified | - | FM, PCR | - | Gyeongbuk | Lee, 2004 |
Table 1. Continued

| Plant host            | Associated disease                  | ‘Ca. Phytoplasma’ Phytoplasma group | Evidence of identity* | Accession number | Region (province) | Selected references            |
|-----------------------|-------------------------------------|-------------------------------------|-----------------------|------------------|-------------------|------------------------|
| **Liliaceae**          |                                     |                                     |                       |                  |                   |                        |
| *Lilium longiflorum* (Lily) | Lily flattened stem (Ph-lily)       | ‘Ca. P. solani’                     | 16SrXII-A             | RFLP, SA         | Gyeonggi, Jeju    | 
|                        |                                     |                                     |                       |                  |                   | Chung and Jeong, 2003    |
| **Moraceae**           |                                     |                                     |                       |                  |                   |                        |
| *Morus alba* (Mulberry) | Mulberry dwarf (MD)                 | ‘Ca. P. asteris’                    | 16SrI                 | EM, SA           | Chonbuk, Gyeongbuk, Han and Cha, 2002 |
| **Oleaceae**           |                                     |                                     |                       |                  |                   |                        |
| *Chionanthus retusus* (Snow-flower fringe) | Snow-flower fringe tree dwarf (SFTD) | ‘Ca. P. asteris’                   | AY/AY                | RFLP, SA         | NA                 | Lee, 2004               |
| *Fraxinus sieboldiana* (Japanese Ash) | Angustata ash witches’ broom (AAshWB) | ‘Ca. P. asteris’                   | AY/AY                | RFLPSA           | AB693130           | Yea and Lee, 2002; Lee et al., 2012 (GB) |
| *F. rhynchophylla* (Ash) | Ash witches’ broom (AshWB)         | ‘Ca. P. asteris’                    | AY/AY                | SA               | NY66302           | Han, 2005               |
| *Forsythia sp.* (Forsythia) | Forsythia witches’ broom (F-WB)   | unclassified                        |                       | -                | RFLP, SH           | Gyeonggi               |
|                       |                                     |                                     |                       |                  |                   | Han et al., unpublished |
| *Ligustrum japonicum* (Wax-leaf privet) | Wax-leaf privet witches’ broom (WPrWB) | ‘Ca. P. zizyphi’                   | EY/JWB               | RFLP, SA         | AB293422           | Gyeongbuk, Jeju         |
| *L. lucidum* (Chinese privet) | Chinese privet witches’ broom (CPrWB) | ‘Ca. P. zizyphi’                   | EY/JWB               | SA               | NA                 | Lee, 2004               |
| *L. obtusifolium* (Ovutsifolium privet) | Privet witches’ broom (PrWB)       | ‘Ca. P. zizyphi’                   | EY/JWB               | EM, SA           | NA                 | Gyeongbuk, Jeju         |
| *L. ibota* (Microphylla privet) | Microphylla privat witches’ broom (MPWB) | unclassified                        | -                    | EM               | -                  | Chonbuk; Chai and Kim, 1989 |
| *L. ovalifolium* (Oval-Leaved privet) | Ovalifolia privat witches’ broom (OPrWB) | unclassified                        | -                    | EM, FM           | -                  | Chonbuk, Chungnam      |
| *L. foliosum* (Korean privet) | Korean privat witches’ broom (KPrWB) | ‘Ca. P. zizyphi’                   | EY/JWB               | SA               | NA                 | Gyeongbuk (Ulleung)     |
| *Syringa vulgaris* (Lilac) | Lilac witches’ broom (LWB)         | ‘Ca. P. zizyphi’                   | -                    | RFLP, SA         | NA                 | Gyeongbuk               |
| **Paulowniaceae**      |                                     |                                     |                       |                  |                   |                        |
| *Paulownia coreana* (Paulownia) | Paulownia witches’ broom (PaWB)   | ‘Ca. P. asteris’                    | AY/AY                | RFLP, SA         | AF279271           | Gyeonggi               |
|                       |                                     |                                     |                       |                  |                   | Han et al., 2001      |
| *P. tomentosa* (Princess tree) | Paulownia witches’ broom (PaWB)   | ‘Ca. P. asteris’                    | AY/AY                | RFLP, SA         | AB693131           | Gyeonggi, Gyeongbuk    |
|                       |                                     |                                     |                       |                  |                   | Han and Cha, 2001; Lee et al., 2012 (GB) |
| **Pedaliaceae**        |                                     |                                     |                       |                  |                   |                        |
| *Sesamum indicum* (Sesame) | Sesame yellow dwarf (SeYD)         | ‘Ca. P. asteris’                    | AY/AY                | EM, SA           | NA                 | Gyeongbuk, Gyeongnam   |
|                       |                                     |                                     |                       |                  |                   | Lee, 2004               |
| **Plantaginaceae**     |                                     |                                     |                       |                  |                   |                        |
| *Plantago lanceolata* (Ribwort plantain) | Leechwort dwarf (LwD)             | ‘Ca. P. pruni’                      | WX/WX                | SA               | NA                 | Gyeongbuk               |
|                       |                                     |                                     |                       |                  |                   | Lee, 2004               |
| *P. asiatica* (Chinese plantain) | Asian plantain witches’ broom (PIWB) | ‘Ca. P. pruni’                      | WX/WX                | SA               | NA                 | Gangwon                |
|                       |                                     |                                     |                       |                  |                   | Lee, 2004               |
| **Plumbaginaceae**     |                                     |                                     |                       |                  |                   |                        |
Table 1. Continued

| Plant host | Associated disease | "Ca. Phytoplasma" | Phytoplasma group | Evidence of identity | Accession number | Region (province) | Selected references |
|------------|--------------------|-------------------|-------------------|---------------------|------------------|-------------------|-------------------|
| Poaceae    |                    |                   |                   |                     |                  |                   |                   |
| *Phyllostachys bambusoides* (Japanese timber bamboo) | Bamboo witches’ broom (BWB) | ‘Ca. P. asteris’ | AY/AY | SA | NA | Chonbuk, Chonnam, Chungnam, Gyeongbuk, Gyeongnam | Lee, 2004 |
| *Phyllostachys nigra* (Black bamboo) | Henonis bamboo witches’ broom (HBWB) | ‘Ca. P. asteris’ | AY/AY | SA | AB242433 | Chonnam, Chungnam, Gyeongbuk, Gyeongnam | Jung et al., 2006 |
| *Sasa borealis* (Northern bamboo) | Sasa witches’ broom (SaWB) | ‘Ca. P. asteris’ | AY/AY | SA | AB293421 | Chonnam, Gyeongnam | Jung and Kim, 2009 (GB) |
| Rhamnaceae |                    |                   |                   |                     |                  |                   |                   |
| *Zizyphus jujuba* (Jujube) | Jujube witches’ broom (JWB) | ‘Ca. P. ziziphi’ | EY/JWB | SA |                  |                   |                   |
|           | Jujube yellow leaf roll (JYLR) | ‘Ca. P. ziziphi’ | EY/JWB | SA | NA | Chonbuk | Lee et al., 2009 |
|           | Wild jujube witches’ broom (WJWB) | ‘Ca. P. ziziphi’ | EY/JWB | SA | NA | Gyeongbuk | Lee, 2004 |
|           | Spinosa witches’ broom (SJWB) | ‘Ca. P. ziziphi’ | EY/JWB | SA | NA | Gyeongbuk | Lee, 2004 |
| *Hovenia dulcis* (Oriental raisin) | Japanese raisin witches’ broom (JRWB) | ‘Ca. P. ziziphi’ | 16SrV-B | SA | AB442218 | Chonbuk | Kamala-Kannan et al., 2011 |
| Sapindaceae |                    |                   |                   |                     |                  |                   |                   |
| *Koelreuteria paniculata* (Goldenrain tree) | Goldenrain stunt (GRP) | ‘Ca. P. asteris’ | 16SrI-B | SA | EU430729 | Chonbuk | Kamala-Kannan et al., 2010 |
| Rosaceae   |                    |                   |                   |                     |                  |                   |                   |
| *Rubus crataegifolius* (Raspberry) | Rubus witches’ broom (RWB) | unclassified | - | EM | - | Gyeongbuk | Lee and Yea, 1992 |
| *Crataegus pinnatifida* (Chinese hawthorn) | Hawthorn witches’ broom (HaWB) | unclassified | - | EM, PCR | - | Gyeongbuk, Gyeongnam | Yea and Lee, 1997 |
| *Prunus salicina* (Chinese plum) | Plum witches’ broom (PluWB) | unclassified | - | Symptom | - | Gyeongbuk | Lee and Kim, 1994 |
| Solanaceae |                    |                   |                   |                     |                  |                   |                   |
| *Petunia* (Petunia) | Petunia flat stem (PFS-K) | ‘Ca. P. asteris’ | AY | SA | EU267779 | Gyeonggi | Chung and Huh, 2008 |
| *Solanum tuberosum* (Potato) | Potato witches’ broom (PWB) | ‘Ca. P. trifolii’ | EY/CP | SA | AB076404 | Gangwon, Jeju | Hahn et al., 2001; Jung et al., 2003a |
| Vitaceae   |                    |                   |                   |                     |                  |                   |                   |
| *Ameloplasis brevipediculata* (Porcelain berry) | Porcelain vine witches’ broom (PvWB) | ‘Ca. P. asteris’ | AY/AY | SA | AB693126 | Gyeongbuk (Ulleung) | Lee et al., 2012 (GB) |
| *Vitis amurensis* (Amur grape) | Amur grape witches’ broom (AGWB) | ‘Ca. P. asteris’ | AY/AY | SA |                  | Gyeongbuk (Ulleung) | Lee, 2004 |
| *Vitis vinifera* (Grape vine) | Grapevine little leave | - | 16SrV | RFLP, SA | NA | Gyeongbuk | Kim et al., unpublished |

Evidence of phytoplasma: EM, electron microscopy; FM, fluorescence microscopy; PCR, polymerase chain reaction; RFLP, RFLP patterns of PCR-amplified 16S rRNA gene; SA, sequence analysis of 16S rRNA gene; SH, Southern hybridization; NA, sequence not available; GB, GenBank data
and other crops. A total of 46 plant species have been affected by the phytoplasmas and those plants belong to 25 plant families (Table 1). Most phytoplasmas have been identified from the plants belong to two families, the Oleaceae and the Asteraceae. The widest host ranges (25 plant species) have been associated with AY phytoplasmas including medicinal plants (e.g. hare’s ear, mulberry), vegetables (e.g. lettuce, onion, water dropwort), ornamentals (e.g. Japanese spurge, chrysanthemum, poinsettia), shrubs (sumac, lilac) and fruit trees (jujube, chestnut) which belong to 15 plant families (Back et al., 2010; Chung and Choi, 2010; Chung and Kim, 2005; Han and Cha, 2001; Lee, 2004; Lee et al., 2009). Elm yellows phytoplasmas have been associated with 10 species of trees belonging to two families, the Oleaceae and the Rhamnaceae. Nine plant species belonging to five families have been affected by western X phytoplasmas. Stolbur phytoplasmas have been identified from two floral plants; chrysanthemum (Asteraceae) and lily (Liliaceae) (Chung and Jeong, 2003; Chung and Kim, 2005). Clover proliferation phytoplasma has been reported from lespedeza (Fabaceae) and potato (Solanaceae) (Jung et al., 2003a; Kim and Jung, 2007). Some plants such as chrysanthemum, chestnut and jujube are infected by two different phytoplasma groups. Chung and coworkers reported two groups of phytoplasmas, AY and stolbur in chrysanthemum from two geographically distinct locations, in northern and southern parts of Korea (Chung and Kim, 2005). Mixed infection of phytoplasmas (16S rDNA I and V group) on jujube witches’ broom disease had been identified by Lee and coworkers (Lee et al., 2009). The mixed infection was assumed to be due to the same insect vector (Hishimonus sellatus) which is able to transmit both of these two phytoplasma groups. Natural insect vectors species have a large influence the plant host range for phytoplasma (Hogenhout et al., 2008).

‘Candidatus Phytoplasma’ species

The phylogenetic analysis of all available Korean phytoplasma 16S rRNA gene sequences showed that the native phytoplasmas belong to six species of ‘Ca. Phytoplasma’; ‘Ca. P. asteris’, ‘Ca. P. ziziphi’, ‘Ca. P. trifolii’, ‘Ca. P. castaneae’, ‘Ca. P. pruni’* and ‘Ca. P. solani’* [* is an incidental citation and does not constitute prior citation (Lapage et al., 1992)] (Figure 1). Jung and coworkers had firstly proposed as the novel taxon as ‘Ca. P. castaneae’ for the chestnut witches’ broom (AB054986) phytoplasma (Jung et al., 2002a) and ‘Ca. P. ziziphi’ jujube witches’ broom (AB052879) (Jung et al., 2003b) following International Research Programme for Comparative Mycoplasmology adoption of a taxonomic rule previously established for recording properties of uncultured organisms (Murray and Schleifer, 1994). The existence of ‘Ca. P. solani’ association with lily stem flattening disease was reported by Chung and Jeong (2003). Association of ‘Ca. P. pruni’ association with yellow dwarf disease of Aster glehni var. hondoensis was reported in Ulleungdo (Jung and Lee, 2004). The association of ‘Ca. P. trifolii’ with witches’ broom disease of leafy lespedeza was observed in Pyeongchang-gun (Kim and Jung, 2007).

Fig. 1. Phylogenetic tree constructed by neighbor joining method of the 16S rRNA gene sequences from Korean phytoplasmas (bold font) and those of 27 previously described ‘Candidatus Phytoplasma’ retrieved from the Genbank. Acholeplasma laidlawii was used as an outgroup. The tree was constructed with a 100-replicate bootstrap search (only values above 80% are shown) using MEGA4 software (Tamura et al., 2007). The bar represents a phylogenetic distance of 1%.*According to Rule 28b of the Bacteriological Code, this is an incidental citation and does not constitute prior citation (Lapage et al., 1992).
**Geographic distribution and insect vectors**

In Korea, phytoplasma diseases exist in every province including Jeju and Ulleung Islands, and many diseases were reported especially from Gyeongbuk and Chonbuk provinces. This suggests that intensive research has been conducted on phytoplasma diseases in those areas, and that more research on phytoplasmas is needed in other provinces. ‘Ca. P. asteris’ and ‘Ca. P. ziziphi’ associated diseases are distributed in every province, probably related to the distribution of insect vectors for those two phytoplasma species. The rhombic-marked leafhopper, *Hishinomus sellatus* is a specific insect vector for JWB phytoplasma (Jung et al., 2003b) and it is also able to transmit SuWB and MD phytoplasmas (La and Woo, 1980; La et al., 1984). This hopper may be the main factor in abundance of ‘Ca. P. asteris’ and ‘Ca. P. ziziphi’ associated diseases throughout the country. In addition, other insect vectors reported for aster yellows phytoplasma include the tobacco leaf bug, *Cyrtopeltis tenuis* (La and Bak, 1994); the leafhopper *Empoasca* sp. (Yeo et al., 1994) that can transmit PaWB; and the polyphagous leafhopper, *Macrosteles striifrons* (*M. orientalis*) that is presumed to be a vector of water Phytoplasma (*Woo et al., 2011*). The presence of large numbers of AY associated diseases suggests that there may be other natural vectors which are able to transmit the AY phytoplasmas. In northern and eastern parts of the country, ‘Ca. P. pruni*’ associated diseases are observed and *Ophiola flavopicta* is the vector for one of ‘Ca. P. pruni*’ associated diseases; *cnidium* witches’ broom phytoplasmas (Lee, 1994). The diseases associated with ‘Ca. P. trifoli*’ have been described from only Gangwon province and Jeju Island, and the insect vector for ‘Ca. P. trifoli*’ could not yet be identified. To date, ‘Ca. P. castaneae’ appears to be a host specific phytoplasma that has only been observed on chestnut trees in Gyeongnam and Chonbuk. The insects that vector chestnut witches’ broom phytoplasmas are still unknown. Since many important diseases are transmitted and distributed by insect vectors, research on finding natural vectors will be very important in designing effective control measures for phytoplasma associated diseases. Research studies of phytoplasma-vector relationships or interactions are still needed in Korea.

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**Conclusion**

This review presents the progress in differentiating and classifying the phytoplasmas reported in Korea over the last three decades. Generally, the 16S rRNA gene sequence and RFLP analysis has been widely applied in the characterization and identification of phytoplasmas. Examined total of 63 phytoplasma diseases can be attributed to one of six presumptive species ‘Ca. Phytoplasma’ on the basis of 16S rRNA gene sequences. Diversity of AY group phytoplasmas belonging to 16SrI-B subgroups has been observed and these phytoplasmas have been reclassified on the basis of interoperon heterogeneity. Likewise, the second largest disease group induced by ‘Ca. P. pruni*’ should be investigated to determine their phylogenetic diversity. Besides, some phytoplasma diseases which were confirmed only by symptoms or EM observation still remain to be classified at the molecular level (Table 1). Information concerning vector-phytoplasma and vector-plant relationships or interactions is necessary for improved understanding of phytoplasma-associated diseases. Although several genome projects have been started in the world in the late 1990s, only four phytoplasma genomes have been fully sequenced including those of two ‘Ca. P. asteris’ strains, and strains of ‘Ca. P. mali’ and ‘Ca. P. australiensis’ (Bai et al., 2006; Kube et al., 2008; Oshima et al., 2004; Tran-Nguyen et al., 2008). In our laboratory, phytoplasma genome sequencing, especially from woody plants affected by jujube witches’ broom phytoplasma, ‘Ca. P. ziziphi’, is currently being conducted. Moreover, for understanding host-phytoplasma interactions, it is important to identify the function of membrane proteins or secreted proteins encoded in the phytoplasma genome. Recently, Namba and coworkers have reported one secreted protein encoded in the phytoplasma genome named as TENGU, which induces witches’ broom and dwarfism (Namba, 2011). Like TENGU, other virulence factors of phytoplasmas are also challenges for researchers.

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