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Present scenario of phytoplasma diseases in India

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Introduction

Phytoplasmas are cell wall-deficient, pleomorphic prokaryotes belonging to the class Mollicutes. They are enclosed by a trilaminar membrane and are primarily associated with plant diseases characterized by yellowing, stunting, witches'-broom, phyllody, and virescence symptoms. Owing to their symptomatology and insect-mediated transmission, phytoplasma-associated diseases were initially presumed to be caused by viruses. However, the pioneering work of Doi *et al.* (1967) demonstrated that mulberry dwarf disease was associated with phloem-inhabiting, cell wall-less microorganisms, which were subsequently designated as mycoplasma-like organisms (MLOs) and later recognized as phytoplasma. They are obligate parasites that inhabit the phloem tissues of plants and the haemolymph of their insect vectors, where they survive within osmotically protected environments. Their genomes consist of double-stranded DNA and are among the smallest known among plant pathogenic bacteria, ranging from approximately 0.53 to 1.0 Mb. Despite their reduced genome size, phytoplasmas contain a relatively high proportion of repetitive DNA elements and mobile genetic sequences, accounting for nearly 25% of their genomic content. The absence of a cell wall confers intrinsic resistance to antibiotics that target cell wall biosynthesis, such as penicillins and cephalosporins. In contrast, treatment with tetracycline antibiotics has been shown to temporarily suppress disease symptoms by inhibiting protein synthesis, as reported by Ishie *et al*. (1967).

More than five decades after their discovery, phytoplasma-associated diseases continue to expand in distribution and economic significance worldwide, with an estimated 700-1000 diseases reported across diverse plant hosts. In India, phytoplasmas have been identified in more than 163 plant species, with a substantial proportion of diseases attributed to members of the Aster Yellows group (16SrI) and Peanut Witches'-Broom group (16SrII) (Tiwari *et al*., 2023). Given their broad host range, complex epidemiology, and increasing agricultural impact, a comprehensive understanding of the diversity and distribution of phytoplasma diseases is essential. Therefore, this review discusses the host range and diversity of phytoplasma-associated diseases reported in India.

Classification of Phytoplasmas

The taxonomy and classification of phytoplasmas are primarily based on molecular and phylogenetic analysis because these organisms lack distinctive morphological and structural characteristics and remain unculturable in conventional bacteriological media. Based on analyses of 16S rRNA gene sequences and other conserved housekeeping genes, phytoplasmas have been assigned to the class Mollicutes and placed within the provisional genus *'Candidatus Phytoplasma'* (Bertaccini, 2019). Prior to the advent of molecular diagnostic tools, phytoplasmas were classified according to symptom expression, host range, serological properties, and insect vector specificity. However, these criteria often produced inconsistent and unreliable classifications due to the extensive overlap in biological characteristics among phytoplasma strains.

The development of molecular techniques, particularly polymerase chain reaction (PCR), nested PCR, and restriction fragment length polymorphism (RFLP) analysis of the 16S rRNA gene, significantly improved the accuracy and reliability of phytoplasma taxonomy. According to the current taxonomic criteria, a phytoplasma strain may be designated as a novel *'Candidatus* Phytoplasma' species when its 16S rRNA gene sequence shares less than 98.65% similarity with that of previously described species, replacing the earlier threshold of 97.5%. In addition to 16S rRNA-based classification, whole-genome approaches such as Average Nucleotide Identity (ANI) and Overall Genome Relatedness Indices (OGRI) are increasingly being employed to resolve phylogenetic relationships and delineate phytoplasma species with greater precision (Kirdat *et al*., 2023).

The complete genome sequence of the Onion Yellows phytoplasma mild strain, reported in 2004, marked a significant milestone in phytoplasma research and provided valuable insights into genome organization, evolution, and pathogenicity. Since then, the genomes of more than 40 phytoplasma strains representing diverse taxonomic groups have been sequenced. Based on 16S rRNA gene RFLP profiles, phytoplasmas are currently classified into more than 37 major 16Sr groups and over 150 subgroups worldwide, reflecting their remarkable genetic diversity and broad host range (Wei and Zhao, 2022; Zhao and Wei, 2025).

Symptomatology

Phytoplasma-infected plants exhibit a wide range of symptoms depending on the host species and the phytoplasma group involved. In cereal crops, common symptoms include yellow dwarf and orange leaf in rice, chlorosis with elongated streaks and stunting in wheat, and leaf reddening in maize. In sugar crops, phytoplasma infections are associated with grassy shoot disease, white leaf disease, and orange leaf syndrome in sugarcane, witches' broom in sugar beet, and bunchy shoot disease in stevia (Kumar *et al*., 2015a). Several fruit crops also exhibit characteristic phytoplasma-associated symptoms. These include rosetting and little leaf in ber (Indian jujube), witches' broom in acid lime, decline and leaf reddening in peach, dieback accompanied by axillary shoot proliferation in papaya, leaf rolling and necrosis in litchi, and phyllody in sapota. These symptoms have been associated with phytoplasma groups belonging to 16SrI, 16SrII, 16SrV, 16SrVI, 16SrXI, and 16SrXIV.

Disease severity is often exacerbated by mixed infections involving phytoplasmas and other pathogens such as viruses or rickettsia-like organisms (RLOs). Such co-infections accelerate disease development and can lead to rapid plant decline.

For example, co-infection of *'Candidatus* Phytoplasma *asteris'* with RLOs has been reported to cause severe yellowing symptoms in several regions of Tamil Nadu (Valarmathi *et al.,* 2013). Phytoplasma-associated diseases are widely distributed among vegetable, ornamental, plantation, pulse, and oilseed crops. Among plantation crops, coconut root wilt disease, first reported in Kerala, is one of the most economically important phytoplasma-associated diseases and has been reported to reduce crop productivity by approximately 35-85% (Prabhakar *et al.,* 2025).

The widespread occurrence and progression of phytoplasma diseases are largely attributed to their efficient transmission by phloem-feeding insect vectors, including leafhoppers, planthoppers, psyllids, and lace bugs. Following acquisition from infected plants, phytoplasmas colonize the insect's gut, haemolymph, and salivary glands, enabling persistent transmission to healthy hosts. Furthermore, the survival of phytoplasmas in weed reservoirs during the off-season, coupled with rapid vector-mediated dissemination and their exclusive habitation within the plant vascular system, poses significant challenges for effective disease management.

Diversity and Distribution of Phytoplasma Diseases in India

Phytoplasma-associated diseases have been reported from 23 states across India and are widely distributed among cultivated crops, ornamental plants, forest species, and weeds. These diseases are responsible for substantial economic losses due to reductions in crop yield and quality. Although numerous phytoplasma diseases have been documented, only a limited number have been investigated comprehensively. The incidence of phytoplasma diseases is comparatively higher in the southern and northern regions of India than in the central and eastern parts of the country. A considerable diversity of phytoplasma diseases has been recorded in ornamental plants, weeds, flower crops, vegetables, spices, and medicinal plants (Fig: 1). Among commercial crops, sugarcane, bamboo, and sandalwood are severely affected by diseases such as grassy shoot, witches' broom, and sandal spike disease, respectively. Sandal spike disease represents one of the earliest recorded phytoplasma-associated diseases in India and was first reported from the Coorg district of Karnataka during the early twentieth century. Sugarcane grassy shoot disease, caused by *Candidatus* Phytoplasma *sacchari* belonging to the 16SrXI group, remains one of the most destructive diseases affecting the sugar industry in India. Similarly, several bamboo species cultivated across eight states have been reported to exhibit symptoms including witches' broom, shoot proliferation, yellowing, and little leaf.

Molecular characterization based on 16S rRNA gene sequencing has revealed a wide diversity of phytoplasma taxa in India. Among the identified ribosomal groups, the aster yellows group

(16SrI) is the most prevalent and has been associated with more than 70 host plant species, followed by the peanut witches' broom group (16SrII) infecting 44 species, the clover proliferation group (16SrVI) infecting 18 species, and the rice yellow dwarf group (16SrXI) infecting 15 species. Sequence analyses have confirmed the occurrence of several phytoplasma species, including *'Candidatus* Phytoplasma *asteris'*, *'Ca.* P. *aurantifolia'*, *'Ca.* P. *ulmi'*, *'Ca.* P. *trifolii'*, *'Ca.* P. *phoenicium'*, *'Ca.* P. *sacchari'*, *'Ca.* P. *oryzae'*, and *'Ca.* P. *cynodontis'* in diverse agro-ecosystems of India.

To date, nearly 40 flowering plant species infected by phytoplasmas belonging to six major ribosomal groups - 16SrI (aster yellows), 16SrII (peanut witches' broom), 16SrVI (clover proliferation), 16SrIX (pigeon pea witches' broom), 16SrXI (rice yellow dwarf), and 16SrXIV (Bermuda grass white leaf) - have been reported from different regions of the country (Rao, 2021). Several phytoplasma diseases have emerged as major threats to agricultural production, including brinjal little leaf, sesame phyllody, sugarcane grassy shoot and white leaf, sandal spike, chickpea stunt, cowpea phyllody, tomato big bud, stone fruit phytoplasma diseases, bamboo witches' broom, and various phytoplasma-associated disorders of ornamental plants. These diseases continue to emerge and re-emerge, highlighting the need for sustained surveillance, molecular characterization, and integrated disease management strategies.

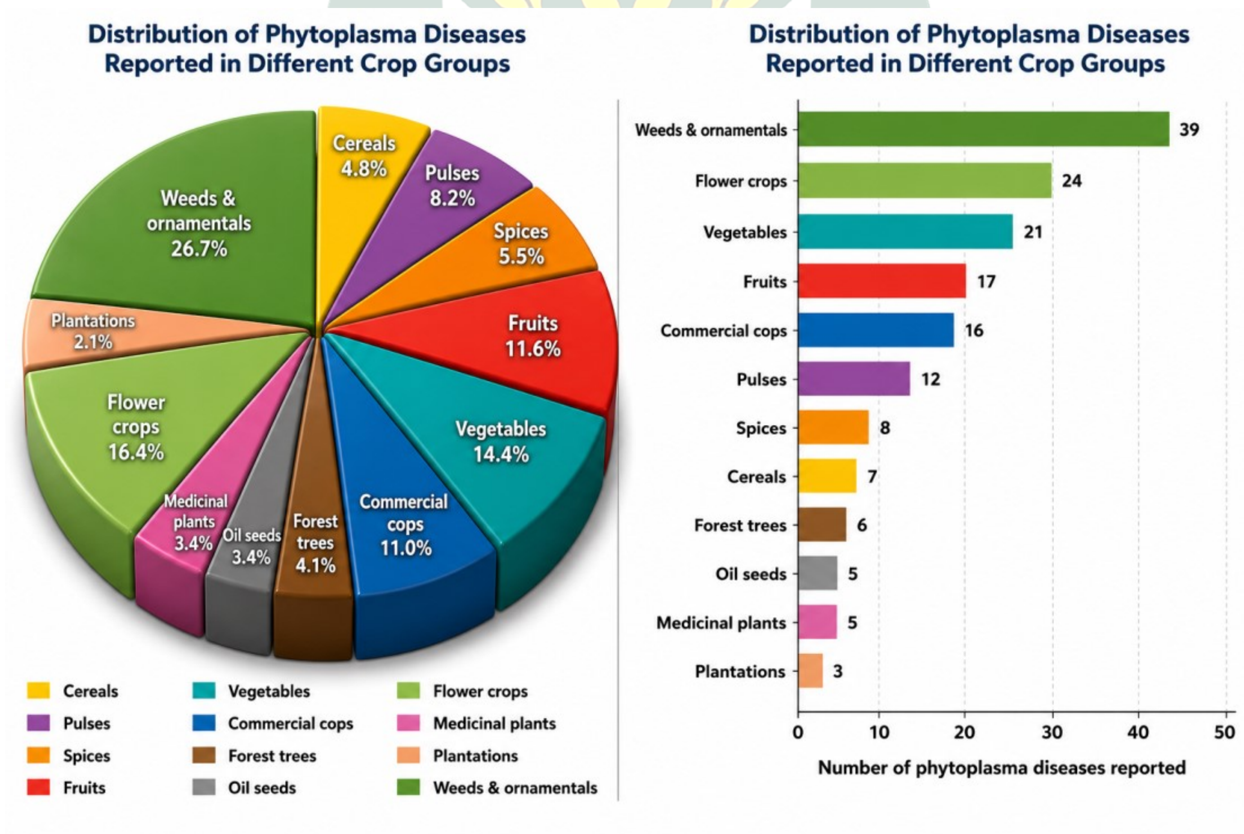

Fig 1: Distribution of phytoplasma diseases reported in various crops in India

Current trends in management

Management of phytoplasma diseases is challenging because phytoplasmas are phloem-limited, unculturable bacteria transmitted mainly by leafhoppers, planthoppers and psyllids. Consequently, management relies on integrated, sustainable and preventive approaches rather than conventional disease control methods (Wang *et al.,* 2024).

1. Use of Healthy Planting Materials and Field Sanitation

Using certified disease-free planting materials is one of the most effective strategies to prevent disease spread, particularly in vegetatively propagated crops such as sugarcane, coconut and arecanut. Removal of infected plants, pruning symptomatic branches and eliminating weed hosts help reduce pathogen reservoirs. In India, rouging of diseased plants is commonly practiced in sesame phyllody, sugarcane grassy shoot and coconut root wilt diseases (Rao *et al*., 2020).

2. Integrated Vector Management

Since phytoplasmas are transmitted by insect vectors, controlling vector populations is essential. Integrated vector management combines cultural, biological and chemical methods, including field sanitation, weed removal, crop rotation and synchronized planting. Excessive insecticide use should be avoided because it can cause environmental pollution and insecticide resistance. Climate variability, especially monsoon conditions, can influence vector populations and disease outbreaks in India (Ablormeti *et al*., 2025; Wang *et al.,* 2024).

3. Molecular Diagnostics and Disease Surveillance

Early and accurate diagnosis is critical because phytoplasma symptoms often resemble nutrient deficiencies or viral infections. Advanced molecular techniques such as nested PCR, qPCR, LAMP and next-generation sequencing (NGS) enable precise identification at early infection stages. Strengthening genomic surveillance and digital databases can improve disease monitoring and early warning systems (Wang *et al*., 2024; Wei *et al.*, 2024).

4. Development of Resistant Varieties

Developing resistant cultivars offers a sustainable long-term solution, although breeding remains difficult due to complex interactions among host plants, insect vectors and phytoplasmas. Advances in genomics, marker-assisted breeding and CRISPR/Cas genome editing provide opportunities to enhance plant resistance and improve immunity (Ain *et al*., 2025).

5. Biological Control

Beneficial microorganisms such as endophytic bacteria and fungi can promote plant growth, induce systemic resistance and improve tolerance to stresses. These microbial inoculants may indirectly suppress phytoplasma diseases and reduce dependence on chemical pesticides. However, further field validation under Indian conditions is required before large-scale adoption (Kumar *et al.,* 2025).

6. Emerging Technologies

Novel approaches such as RNA interference (RNAi), nanotechnology, remote sensing, artificial intelligence and precision agriculture are emerging as promising tools for phytoplasma management. These technologies can improve disease detection, vector control and overall management efficiency while supporting sustainable agriculture (Halder *et al*., 2022; Xu *et al*., 2026).

Conclusion

Phytoplasma diseases have emerged as a significant threat to agricultural productivity due to their wide host range, efficient insect-mediated transmission and complex epidemiology. In India, their increasing occurrence across diverse crops highlights the need for continuous surveillance and early diagnosis. Recent advances in molecular diagnostics, genomics and precision agriculture have improved our understanding and management of these pathogens. However, the absence of resistant varieties and the challenges associated with controlling insect vectors necessitate integrated and sustainable management approaches. Combining healthy planting materials, vector management, biological control and emerging technologies will be essential for effective long-term disease management. Strengthening research, disease monitoring and farmer awareness programmes will further help mitigate the impact of phytoplasma diseases on Indian agriculture.

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