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Nano-Management of Phytoplasma Diseases in Horticultural Plants: A Short Communication

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PHYTOPLASMA and its associated plant diseases is a serious threat to the production of several horticultural crops, which leads to severe losses in the yield worldwide. Phytoplasmas could be considered "one of the most molecularly enigmatic genera of plant pathogens" due to the lack in complete knowledge about "phytoplasma-host–pathogen–vector interactions" and the inability to culture them successfully *in vitro*. The main problem of phytoplasma is the serious economic losses in diverse cultivated crops, which associated with phytoplasma diseases particularly the horticultural crops (i.e., vegetables, fruits, and ornamental plants), as well as oil crops, cereals, sugarcane, cassava, spices, etc. Several reports have been published about the impacts of phytoplasma diseases on different horticultural crops all over the world, which may cause economic losses up to 100% under severe epidemics like phytoplasma associated-disease of grape in Europe "Flavescence dorée". Therefore, the management of phytoplasma has gained a great concern worldwide on all levels. This is a call by EBSS journal for articles about the phytoplasmas and their impacts on horticultural crops as well as any further studies on epidemiology and developing epidemiological models for spreading and distribution alarming phytoplasma diseases, which should be carried out to devise strategies against phytoplasma epidemics. There are many open questions regarding phytoplasma in horticultural crops especially the very complex relationship in the host–pathogen–insect interactions, as well as the management of phytoplasma-infected crops. Can nano-diagnosis and control be being an effective in management of phytoplasma diseases and their pathogens particularly at the early stage?

Keywords: Plant pathogens, Horticultural crops, *Candidatus* Phytoplasma, Nanotechnology

Introduction

Diseases associated with phytoplasma have significant economic and ecological impacts due to their local impact and/or widespread distribution (Marcone 2015; Tomkins et al. 2018; Hemmati et al. 2021a). Phytoplasmas are wall-less bacterial plant pathogens of the class *Mollicutes*, which could be spread by using infected vegetative propagating materials but cannot transmit mechanically (Marcone et al. 2018; Laimer and Bertaccini 2019; Bertaccini et al. 2019). Several symptoms of phytoplasma on plants including witches' brooms, phyllody, virescence, rosetting, off-season growth, and brown discoloration of phloem tissue (Hemmati et al. 2021a). Based on the kind or crop, phytoplasmas are currently classified within the provisional genus '*Candidatus* Phytoplasma' based primarily on 16S rDNA sequence analysis, which differ based on region as reported in Iran (Karimzade et al. 2018; Abbasi et al. 2019; Esmaeilzadeh-Hosseini et al. 2019; Ghayeb Zamharir 2018; Hemmati et al. 2019; Salehi et al. 2018, 2019, 2020), Mozambique (Bila et al. 2019a), Lebanon (Kumar et al. 2019), Austria and Hungary (Riedle-Bauer et al. 2019), Oman (Al-Subhi et al. 2018, 2019; Hemmati et al. 2020), Syria (Khalil et al. 2019),

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Turkey (Çaglar et al. 2019), Iraq (Al-Kuwaiti et al. 2019), Jordan (Salem et al. 2019), India (Reddy et al. 2021), Argentina (Bongiorno et al. 2020), and Saudi Arabia (Omar et al. 2020). Concerning horticultural crops and phytoplasma, many orchard crops have been recorded as infected by phytoplasma like apple (Görg and Gross 2021), citrus (Hemmati et al. 2021c), apricot (Salehi et al. 2018, 2019), grapes (Babaei et al. 2019; Ghayeb Zamharir and Taheri 2019; Quaglino et al. 2019), date palm (Ghayeb Zamharir and Eslahi 2019), pistachio (Ghayeb Zamharir 2018), papaya (Kazeem et al. 2021), Mexicann lime (Hemmati et al. 2020), and stone fruit trees (Pappi et al. 2020; Zirak et al. 2021).

Therefore, this work is a call for submission articles about phytoplasma research including the physiology, genes, biochemistry, proteins, metabolites, and environment of phytoplasma in horticultural crops as well as the phytoplasma–insect interactions at all levels. Nano-management of phytoplasma also is needed to be discussed as a promising management of control and diagnosis of these phytopathogens.

Phytoplasma and its definition

Phytoplasma could be defined as "*Phytoplasmas are obligate prokaryotic wall-less bacteria, which multiply in isotonic niches of plant phloem tissues and insect haemolymph*" (Kumari et al. 2019, 2021a). Phytoplasma is a unique group of "obligate prokaryotic pathogenic bacteria", which discovered in 1603 for mulberry dwarf disease in Japan (Doi et al. 1967). The main features of phytoplasma may include pleiomorphic shape, lack a cell wall, surrounded by a single membrane, 200–800 nm in diameter and possesses a very small genome of about 680–1530 kb (Rao 2021). The main inhabitation of phytoplasma in infected plants is phloem sieve elements (Hemmati et al. 2021a). Phytoplasmas could be classified as follows under Tenericutes (Phylum), Mollicutes (Class),

Fig. 1. The normal plants of Celosia cristata (photo A) and some forms of phytoplasma infection on these plants photos (B), (C), and (D). These photos were taken in private farm in Egypt .

TABLE 1. The main features of phytoplasma and its related disease on horticultural plants .

Main features (items)	Details concerning phytoplasma item	References
Phytoplasma definition	"*Phytoplasmas are phloem-limited pleomorphic bacteria lacking the cell wall, mainly transmitted through leafhoppers but also by plant propagation materials and seeds*"	Kumari et al. (2019)
Main horticultural hosts of phytoplasmas		
1. Fruit trees	Citrus, papaya, plum, grapevine, pomegranate, apples, and banana	Rao et al. (2020)
2. Vegetable crops	Broccoli, cabbage, chayote, cauliflower, eggplant, strawberry, pepper, and tomato	Bragard et al. (2020)
3. Ornamental plants	Begonias, bougainvillea, celosia, hibiscus, poinsettia, and periwinkle	Marcone et al. (2016); Bedendo and Lopes (2019)
Main features or symptoms of phytoplasma on horticultural crops		
Phytoplasma diseases of vegetable crops	Main symptoms include phyllody, little leaves, big buds, flower virescence, and witches' brooms	Kumari et al. (2019)
Forest and urban trees	Specific symptoms include phyllody, virescence, rosetting, witches' brooms, off-season growth, and brown discoloration of phloem tissue	Marcone et al. (2018)
Symptoms of fruit orchards	Symptoms include leaf yellowing and reddening, decline, little leaf and malformation	Rao et al. (2020)
Some recent "Candidatus Phytoplasma" on horticultural crops		
Witches'broom disease of *Boehmeria pannosa*, in Korea	*Candidatus* Phytoplasma asteris	Han et al. (2021)
Coconut lethal wilt, in India	*Candidatus* Phytoplasma asteris	Babu et al. (2021)
Pepper yellow crinkle, China	*Candidatus* Phytoplasma asteris	Yu et al. (2021)
Spinach flat stem, India	*Candidatus* Phytoplasma asteris	Kumari et al. (2021)
Apricot disease in India	*Candidatus* Phytoplasma asteris	Rao et al. (2020)
Celosia leaf yellowing, India	*Candidatus* Phytoplasma asteris	Panda et al. (2020)
Lime witches' broom in Iran	*Candidatus* Phytoplasma aurantifolia	Hemmati et al. (2021c)
Lime witches' broom in Iran	*Candidatus* Phytoplasma aurantifolia	Rastegar et al. (2021)
Papaya disease in Nigeria	*Candidatus* Phytoplasma convolvuli	Kazeem et al. (2021)
Apple disease in Germany	*Candidatus* Phytoplasma mali	Görg and Gross (2021)
Peach witches'-broom in Iran	*Candidatus* Phytoplasma phoenicium	Salehi et al. (2020)
Citrus HLB-like sym., Brazil	*Candidatus* Phytoplasma pruni	Barbosa et al. (2021)
Grape Bois Noir disease, Italy	*Candidatus* Phytoplasma Solani	Pierro et al. (2020)
Grape Bois Noir disease, Austria	*Candidatus* Phytoplasma Solani	Dermastia et al. (2021)
Ptato *Stylosanthes* little leaf disease in Australia	*Candidatus* Phytoplasma stylosanthis'	Rodrigues-Jardim et al. (2021)
Jujube witches' broom, China	*Candidatus* Phytoplasma ziziphi	Deng et al. (2021)

Acholeplasmataceae (Family), Acholeplasmatales (Order), *Candidatus* Phytoplasma (Genus), as reported by Rao (2021). Phytoplasmas can cause several diseases for over 1000 plant species worldwide including horticultural, and weed species (Rao et al. 2018). The main features of phytoplasma and more information could be found in the **Table 1 and Fig. 1.**

Nano-management of phytoplasma diseases

The integrated management of phytoplasma is considered a disease control approach, which combines the plant resistance as well as biological, cultural, physical, and chemical control strategies in order to keep disease pressure below an economic injury threshold (Bila et al. 2019b). The minimizing use of chemicals in phytoplasma control is an important strategy as well as using all other available management strategies to maintain the level of disease under control (Bila et al. 2019b). The correct identification of plant disease and its timing also is a critical factor of disease management system. The main problem of phytoplasma diseases control and their insect vectors represent in the absent of effective control measurements for the phytoplasma-associated diseases, thus the effective management practices should be adopted (Rao 2021). Beside using the insecticides in minimizing and management of incidence vectors of phytoplasma, there are some management practices including the effective vector control, production of clean propagating materials, weed management and stimulating of plant defenses (Rao 2021). More effective management tools could be used for reducing phytoplasma spread in an environmentally sustainable approach like the biocontrol practices of phytoplasma strains as an alternative control strategy against these diseases (Rao 2021).

The management of phytoplasma diseases is a crucial issue in the agriculture especially the horticultural crops, which represent a main source of global food supply in the world. Thus, many studies have discussed this serious threat for horticultural production including different dimension like sustainable management of phytoplasma diseases (Olivier and Pérez-López 2019), integrated management of phytoplasma diseases (Bianco et al. 2019), management of phytoplasma in vegetable crops (Kumari et al. 2019), and management of phytoplasma diseases in the Middle East (Hemmati et al. 2021a), but using of nanotechnology is still in the enfant stage (Nair and Manimekalai 2021). The management of phytoplasma diseases mainly depends on early detection, use of disease-free planting materials, vector control, and cultivation of resistant varieties, whereas the nano-management depends on the integration of nanotechnology and molecular diagnostics (Nair and Manimekalai 2021). The main phytoplasma diagnostics may include microscopy (TEM and SEM) and serology-based techniques, nested PCR, quantitative PCR, digital PCR, isothermal diagnostics approach or LAMP and nanotechnology (Nair and Manimekalai 2021).

Conclusions

The phytoplasma diseases are well documented in several countries all over the world causing significant economic losses in different crops like eggplant little leaf, sesame phyllody, coconut root wilt, sugarcane grassy shoot, and many ornamentals and vegetable crops. A large number of new phytoplasma strains on several crops have been identified worldwide during last decade, which confirmed that phytoplasma diseases are more diverse than the earlier thought. The main information concerning vector-phytoplasma and their relationships and/or interactions are very important for understanding phytoplasma-associated diseases. The integrated management approaches towards effective biological control of pathogens, developing resistant varieties, RNA interference and indexing of phytoplasmas at early stage in established fruit orchards, vegetatively propagating materials of established certified nurseries and importing materials are also important. Although several benefits of molecular diagnostic techniques as accurate and quick disease detection, the need for using the nano-tools in discovering and diagnosis of phytoplasma diseases is considered a promising approach. This is a call by EBSS for articles focusing on phytoplasma research including original research articles, opinions or short communications, reviews, and modeling approaches. These studies may include physiological, biochemical and genetic aspects of phytoplasma as well as the nano-dimensions, along with phytoplasma–insect interactions at all levels.

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