



## Fusarium species as pathogen on orchids

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### ABSTRACT

The recent surge in demand for exotic ornamental crops such as orchids has led to a rise in international production, and a sharp increase in the number of plant and plant products moving between countries. Along with the plants, diseases are also being transported and introduced into new areas. *Fusarium* is one of the major diseases causing pathogens infecting orchids that is spreading through international trade. Studies have identified several species of *Fusarium* associated with orchids, some are pathogenic and cause symptoms such as leaf and flower spots, leaf or sheath blights, pseudostem or root rots, and wilts. Infection and damage caused by *Fusarium* reduces the quality of plants and flowers, and can cause severe economic losses. This review documents the current status of the *Fusarium*-orchid interaction, and illustrates challenges and future perspectives based on the available literature. This review is the first of *Fusarium* and orchid interactions, and integrates diverse results that both furthers the understanding and knowledge of this disease complex, and will enable the development of effective disease management practices.

### 1. Introduction

Orchids are one of the most highly prized ornamental plants. They are members of the Orchidaceae, a large family of perennial herbs consisting of about 700 genera with over 20,000 species of terrestrial, epiphytic, and saprophytic plants worldwide (Staples and Herbst, 2005). As saprophytes, orchid may sometimes lack chlorophyll, but none are known to be parasitic. Orchids grow most abundantly in tropical and subtropical forests, where they are largely epiphytic; and in temperate climates, select genera thrive in shaded habitats.

Evolutionarily, orchids are among the most advanced group of monocotyledonous plants, with an array of adaptive mechanisms that allow them to thrive in a wide range of environments. Some of the most notable adaptations include specialized structures for water uptake and storage, associations with specific fungi for their nutritional requirements and, mechanisms for pollination and seed germination. For water uptake and storage, orchid roots consist of layers of spongy hydrophilic cells (the velamen), whose primary function is to capture and hold water from the surrounding atmosphere, increase nutrition absorption and reduce water loss from the cortex (Pridgeon, 2006). Other adaptations include the development of highly modified floral structures, intended to attract and deliver pollen to very specific insect pollinators.

Orchids are long-lived herbaceous plants with two growth forms: sympodial growth, where a terminal shoot produces new growth from the old shoot base; or monopodial growth, with a single growing point

on a non-terminal shoot (Hew and Yong, 1997; Staples and Herbst, 2005). Based on the support requirements needed for growth, orchids are also grouped into two types *viz* epiphytic and terrestrial. Epiphytes grow on other plants and obtain moisture and nutrients from plant wastes, the atmosphere, moss and bark by absorption. Terrestrial orchids, on the other hand, are rooted in the soil. A third type, which is a subset of epiphytes, are the Lithophytes. Orchids in this group usually grow on thin layers of detritus on rocks. Orchids are relatively slow-growing, long-term perennial crops, which require two to ten years to attain reproductive maturity. Depending on the type of orchid, mature plants may flower continuously, or only once or twice a year. Flowers may be borne in sprays of long inflorescences, as floral clusters, or as single flowers that can last from one day to more than ten weeks (Hew and Yong, 1997).

Different genera of orchids are bred for their unique blossom characteristics, including color, pattern, size, scent, and shape, and for their spray characteristics, such as length, longevity, and flower numbers that make them marketable (Kamemoto et al., 1999; Lenz and Wimber, 1988). Plants are either grown for cut flower sales or retail as potted ornamental plants (Hew and Yong, 1997).

Due to the high degree of genetic compatibility among different genera and species, hybrids can be easily created. The first artificial orchid hybrid was made in England in 1856 by John Domin. He crossed *Calanthe masuca* with the pollen of *Calanthe furcata* to produce a hybrid, which he called *Calanthe dominii* (Veitch, 1906). Since then the number

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of hybrids registered has grown to approximately 100,000 (Pridgeon, 2006). The great variety of current cultivars however, are those created through artificial hybridization between two or more species, often from different genera (Kishor et al., 2006).

Ornamental orchids first reached Europe from the New World in 1731, and by 1821 they were being grown commercially in greenhouses in London. Today, countries involved in commercial production of orchids include: the United States, Britain, Japan, China, Taiwan, Thailand, Australia and Singapore. In a report published by Thammasiri, Thailand predominates the orchid export market. In 2014, the combined revenue generated by orchid cut-flowers and orchid plants was \$ 82 million (Thammasiri, 2016).

In the United States, most of the orchids grown are not for export. In 2005, 18 million potted orchids were produced in the U. S., and were sold domestically at an average wholesale price of \$8.00 per pot (USDA, 2006). Orchids are currently one of the most important potted ornamental crops in the United States with a total wholesale value of \$288 million (NASS, 2016). In 2015, the largest state producers of potted orchids were California (\$118.5 million), Florida (\$77.8 million), and Hawaii (\$11.3 million), while for cut flower production California (\$6.1 million) was the largest producer followed by Hawaii (\$1.5 million) (NASS, 2016).

The genus *Fusarium*, a large group of filamentous fungi, belongs to family Nectriaceae, and is widely distributed in soil and associated with plants worldwide. It is a cosmopolitan genus with the ability to survive as saprophytes in soil (Burgess, 1981). *Fusarium* spp. can colonize the rhizospheres of various plants and, moreover, enter an endophytic state. *Fusarium* also is an important pathogen of numerous crops and ornamental plants of agricultural and economic importance. The notorious Panama disease of banana, (*F. oxysporum* f. sp. *cubense*), is one of the six most important plant diseases worldwide, responsible for billions of dollars of losses to farmers and perhaps even threatening the existence of the crop (Ploetz, 2015). Head blight of wheat, (*F. graminearum*) and wilt of cotton, (*Fusarium oxysporum* f. sp. *vasinfectum*) are other prominent examples of devastating diseases caused by *Fusarium* species (Rajput et al., 2006). Many popular garden and greenhouse ornamentals also are frequently attacked by different *formae speciales* of *F. oxysporum* along with its sister species such as *F. foetens*, *F. hostae* and *F. redolens* such as aster begonia, carnation, chrysanthemum, gladiolus, lily, and narcissus. These spp. Can damage ornamentals at any stage of production (Gullino et al., 2002). These spp. are very destructive as they can affect almost all the plant organs and produce a broad range of symptoms, e.g., crown and root rots, stalk rots, head and grain blights, and vascular wilts. Once the fungus is introduced into a garden, nursery, greenhouse, or field, it can survive for several years in a variety of soil types, independent of any host plant. This survival ability challenges farm and nursery managers to devise and implement efficient management programs to control pathogenic *Fusarium* species.

*Fusarium* is associated with orchids as both pathogens and non-pathogens throughout the world. The non-pathogenic *Fusarium* species associated with orchids are usually decomposers (Booth, 1971) and/or mutualists, which aid seed germination and seedling coloration (Vujanovic et al., 2000). Non-pathogenic species of *Fusarium* can be used to control *Fusarium* wilt on various crops (Alabouvette et al., 1993). Soils that can suppress *Fusarium* wilt also are rich in populations of non-pathogenic spp. such as *F. oxysporum* and *F. solani* (Louvet et al., 1976; Toussoun, 1975). The incidence of *Fusarium* diseases in orchids has been steadily increased worldwide, and pathogenic *Fusarium* spp. are now considered one of the major limiting factors for the production of high quality orchids (Wedge and Elmer, 2008). Several genera of orchids such as *Dendrobium*, *Cymbidium*, *Phalaenopsis* and *Cattleya* have been shown to be susceptible to infection by *Fusarium* (Burnett, 1985; Hadley et al., 1987; Kim et al., 2002). *Fusarium* species frequently damage seedlings and young shoots (Fig. 1A and B). Young plants are rapidly killed by this pathogen, while surviving plants continue to be adversely affected by the infection. New growth is destroyed by the

pathogen and multiple plant deaths can cause severe losses. *Fusarium* infection typically causes leaf spots, leaf blights or leaf rots, sheath rots, and rots of the shoot tip (apical meristem) (Fig. 1C–F). Flowers also are affected as diseased flowers develop oval and dark brown necrotic spots. Leaves are infected when young, and the severity of the disease depends on the age and moisture levels of the shoots (Kawate and Sewake, 2014; Leonhardt and Sewake, 1999). Foliar symptoms begin with chlorotic 2–5 mm circular leaf spots that turn into necrotic small and sunken brown to blackish-brown leaf spots. In severe infections, these spots coalesce to form blights that sometimes kill the growing point of the shoot (Fig. 1C) (Swett and Uchida, 2015). An arrangement of rows of three to four spots across the leaf blade, is a common characteristic of spots caused by *Fusarium*. These spots typically form close to the cane (Kawate and Sewake, 2014; Leonhardt and Sewake, 1999). Immature sheaths are also very susceptible to infection. Symptoms starts as small, dark spots that turns into blackened sheath rots (Fig. 1D) when plants are grown in moist environments (Leonhardt and Sewake, 1999). Young shoots are highly susceptible and may completely rot if infection occurs at shoot emergence (Fig. 1F). Kawate and Sewake (2014), reported that sometimes only young leaves are affected, and the tip of the cane blackens and die, while older leaves remain green. Such infected shoots produce short canes and no flowers when mature.

The recent emergence of *Fusarium* as a major pathogen of economically important orchids, highlights the need for more information on *Fusarium*. This review compiles and presents comprehensive information of different *Fusarium* species, and their pathogenic relationship with different orchid genera reported worldwide.

## 2. *Fusarium* as pathogen on orchids

*Fusarium* pathogens of orchids have been reported from locations around the world, although the majority of the reports originate from tropical and subtropical regions (Table 1). *Fusarium* species reported to cause foliar and root diseases on orchids include *F. oxysporum*, *F. proliferatum*, *F. solani*, *F. subglutinans*, and *F. fractiflexum*. It also is common to find more than one species occurring at the same location, causing similar disease symptoms (Benyon et al., 1996; Ichikawa and Aoki, 2000; Latiffah et al., 2009; Srivastava, 2014; Swett and Uchida, 2015). In the following section we describe the important *Fusarium* species reported on different orchid genera.

### 2.1. *Fusarium oxysporum*

*Fusarium oxysporum* is a complex species composed of at least 150 host-specific, phytopathogenic species (Armstrong and Armstrong, 1981; Booth, 1971; Fourie et al., 2011) and a vast number of saprotrophic strains. Due to a relatively high level of biodiversity in this species, it has the ability to adapt to environmental changes and form new pathogenic strains over a short period (White et al., 2001). It is also the most economically important species in the *Fusarium* genus, given its numerous hosts and the level of loss that is produced on infected plants. Many *F. oxysporum* isolates appear to be host specific, which has resulted in the subdivision of the species into *formae speciales* and races that reflect the apparent plant pathogenic specialization (Leslie and Summerell, 2006).

Despite the broad host range of the species, host specialization of isolates is the characteristic that attracted the most attention from plant pathologists (Leslie and Summerell, 2006). Isolates with the same or similar host ranges are recognized as a *forma specialis*, with more than 70 *formae speciales* described (Armstrong and Armstrong, 1981; Booth, 1971). Very often, host range is restricted to a few plant species e.g. *F. oxysporum* f. sp. *lycopersici* causes disease only in plants of the genus *Lycopersicon* (Rowe, 1980). However, some *formae speciales* have broader host ranges, e.g. *F. oxysporum* f. sp. *radicislycopersici*, which can cause disease on hosts from multiple plant families, including tomato (*Lycopersicon esculentum*), cucumber (*Cucumis sativus*), zucchini

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