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### First report of the *Brevipalpus*-transmitted (Trombidiformes: Tenuipalpidae) *Orchid fleck dichorhavirus* infecting three ornamentals in Florida

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### Abstract

We describe the first outbreaks of *Orchid fleck dichorhavirus*, belonging to the orchid-infecting subgroup (OFV-Orc), from three unreported hosts: *Liriope muscari*, cv. ‘Gigantea’ (Decaisne) Bailey, *Ophiopogon intermedius* Don and *Aspidistra elatior* Blume (Asparagaceae: Nolinoidaea) in Leon and Alachua Counties, FL. Strains of OFV-Orc infect over 50 plant species belonging to the plant families Orchidaceae, Asparagaceae (Nolinoidaea), and infects *Citrus* (Rutaceae) as citrus leprosis disease. The only known vectors of OFV-Orc are flat mites, genus *Brevipalpus* (Trombidiformes: Tenuipalpidae). Florida has various plants in the landscape which *Brevipalpus* spp. feed on, which are susceptible to infection by OFV-Orc.

Chlorotic ringspots and flecking was seen affecting Liriopogons (*Liriope* spp. and *Ophiopogon* spp.) in Leon County, FL. Nearby *A. elatior* also appeared chlorotic. Local diagnostics returned negative for common plant pathogens, therefore new samples were sent to the Florida Department of Agriculture and Consumer Services (FDACS) and USDA-ARS for identification.

Two orchid-infecting strains of Orchid fleck virus were detected via combinations of conventional RT-PCR, RT-qPCR, Sanger sequencing and High Throughput Sequencing. Amplicons shared 98% nucleotide identity with OFV-Orc1 and OFV-Orc2 available in NCBI GenBank. Coinfections were seen in each county, but single strains of OFV-Orc were seen in *L. muscari* (Alachua, OFV-Orc2) and *A. elatior* (Leon, OFV-Orc1).

Three potential mite vectors were identified via cryo-scanning electron microscopy (Cryo-SEM): *Brevipalpus californicus* (Banks) sensu lato, *B. obovatus* Donnadieu, and *B. confusus* Baker.

In conclusion, *Orchid fleck dichorhavirus* is present in northern Florida, representing a risk for susceptible plants in the southeastern US.

### Keywords:

False spider mite, flat mite, *Brevipalpus*-transmitted viruses, *Liriope*, Nolinoideae, *Ophiopogon*, *Aspidistra*, Ruscaceae, Rutaceae, Asparagaceae, orchid, Orchidaceae, pests, ornamental plants, Orchid fleck virus.

*Orchid fleck dichorhavirus* (OFV) is the type member for the genus *Dichorhavirus*, family *Rhabdoviridae*; a bacilliform, nuclear rhabdovirus composed of two segments of single-stranded, negative-sense RNA which infects plants (Dietzgen et al. 2014, Walker et al. 2018, Amarasinghe et al. 2019). Flat mites from the genus *Brevipalpus* (Trombidiformes: Tenuipalpidae) are the only known vectors of dichorhaviruses (Maeda 1998). *Brevipalpus californicus* (Banks) sensu lato mites are the only group known to transmit OFV in a persistent propagative manner (Kondo et al. 2003).

OFV-infected plants exhibit various symptoms depending on the infected plant species as well as the strain of the OFV associated with the infection (Kubo et al. 2009a), but symptoms typically appear as chlorotic flecks, which ultimately coalesce into larger spots or ringspot patterns .

OFV was first described as infecting *Cymbidium* orchids in Japan (Doi et al. 1977). OFV and OFV-like rhabdoviruses have been reported infecting orchids in Asia, Africa, North America, South America, Europe, and Oceania. The prevalence of OFV and its mite vector is thought to be associated with the movement of infected orchids (Dietzgen et al. 2018a).

OFV naturally infects more than fifty species of Orchidaceae (Kitajima et al. 2010, Peng et al. 2013), some Asparagaceae (Nolinoidaea) (Mei et al. 2016, Dietzgen et al. 2018b), and Rutaceae: (*Citrus*), where it causes citrus leprosis-like symptoms (Roy et al. 2015, 2020, Cook et al. 2019, Olmedo-Velarde et al. 2019). Mechanical transmission of OFV is possible under laboratory conditions to some plants belonging to the plant families Chenopodiaceae, Aizoaceae, Fabaceae, and Solanaceae (Chang et al. 1976, Kondo et al. 2003, Peng et al. 2013).

During June 2020, chlorotic ringspot symptoms were observed on Giant Lilyturf *Liriope* spp., cv. ‘Gigantea’ in a landscape of Leon County, Florida (Fig. 1). *Liriope* belong to a group of plants in the family Asparagaceae, subfamily Nolinoidaea, comprised of grass-like monocotyledonous liliod plants native to southeastern Asia (Chase et al. 2009, Meng et al. 2021). *Liriope* and the closely related *Ophiopogon* Ker Gawler (Asparagaceae: Nolinoidaea) are considered the most important ground cover plant in the southeastern United States (Mcharo et al. 2003).

Viral infections of suspected leaf samples were initially tested at the Plant Disease Diagnostic Clinic at the North Florida Research and Education Center (NFREC) in Quincy, FL. All the samples were tested with one step conventional RT-PCR, and were found negative for begomovirus, carlavirus, potyvirus, tospovirus, and *Cucumber mosaic virus*, *Impatiens necrotic spot virus*, *Tobacco mosaic virus*, and *Tomato spotted wilt virus*.

As initial diagnostics were inconclusive, new samples were collected during July and August of 2020 to collect more of these putatively-infected plants with ringspot symptoms. The plants collected included *Liriope* spp. and *Ophiopogon* spp., as well as *Aspidistra elatior* Blume (Asparagaceae: Nolinoidaea). *A. elatior* was suspected to be infected, due to both its proximity to infected *Liriope* and the presence of unusually chlorotic leaves (Fig. 2). Upon collection, the new samples were sent to the Florida Department of Agriculture and Consumer Services (FDACS) for identification.

The FDACS determined that the pathogen was *Orchid fleck dichorhavirus* using previously published primers and methods to conduct RT-PCR and Sanger sequencing (Kubo 2006a, 2006b, Kubo et al. 2009b, Kubo et al. 2009a, Ramos-González et al. 2015). Orchid subgroup 1, OFV-Orc was identified following the methods described in Kondo et al. (2017). Sequencing demonstrated a shared 98% nucleotide identity with the orchid strain subgroup, OFV-Orc (isolates So and Br with GenBank Accession numbers: AB244418 and MK522807, respectively) (Kondo et al. 2006, 2017).

These samples from FDACS were subsequently retested by the USDA-ARS, in conjunction with tests of fresh samples from both Alachua and Leon counties. The USDA used RT-PCR, RT-qPCR, and High Throughput Sequencing (HTS) in sequence to reconfirm the presence of *Orchid fleck dichorhavirus*. RT-PCR and qPCR with Generic R2-Dicho-GF and R2-Dicho-GR primers amplifed ~800 nt of L-gene (RNA2) amplicon (Roy et al. 2020), and OFV-Orc1 and OFV-Orc2 were detected in both *O. intermedius* and *A. elatior* from Leon County.

HTS reaffirmed the presence of OFV-Orc1 and OFV-Orc2 strains in Leon and Alachua counties (Table 1). HTS results from Leon County revealed that *L. muscari* were coinfected with both strains (OFV-Orc1 and OFV-Orc2), while *A. elatior* were solely infected with OFV-Orc1. HTS of *L. muscari* from Alachua County revealed infections with the OFV-Orc2 strain.

After the initial identification by FDACS of OFV-Orc, mite samples were collected from symptomatic Asparagaceae in Leon county. The majority of mites collected were Tenuipalpid mites (flat mites or false spider mites), a known pest of ornamental plants, some of which are known to act as vectors for plant viruses (Childers et al. 2003, Childers and Rodrigues 2011).

Mite taxonomy is perturbed by the cryptic species complexes which exist in many plant-feeding species of the Acari (Skoracka and Dabert 2010, **Arthur2011?**, **Skoracka2013?**, **Umina1999?**), including tenuipalpid mites from the common genus *Brevipalpus* (**Navia2013?**). Notwithstanding, additional techniques in addition to basic light microscopy can help to find characters necessary to separate species groups, including cryptic species (Beard et al. 2015).

The flat mites collected were initially suspected to belong to *B. californicus* s. l. after inspection with phase contrast microscopy. Subsequent observation via Differential Interference Contrast (DIC) microscopy at FDACS agreed with this tentative identification. Unfortunately, the *B. californicus* s. l. species group, sensu Baker and Tuttle (1987) is suspected to contain cryptic species (Childers and Rodrigues 2011, Rodrigues and Childers 2013) as well.

With this information in mind, new mite samples were collected from symptomatic liriopogons and *A. elatior* in Leon County and sent to USDA-ARS’s Electron and Confocal Microscopy Unit for analysis. Three mite species were recovered and examined under cryo-scanning electron microscopy (Cryo-SEM): *B. californicus* s.l. (Fig. 3), *B. obovatus* Baker and *B. confusus* Donnadieu (Fig. 4).

The first report of OFV in the US is thought to be Ko et al. (1985), who describes nuclear inclusions caused by an undescribed bacilliform rhabdovirus in *Brassia* orchids. The significance of this report is their reference to spoke-wheel configurations of the viral particles (Ko et al. 1985), a sign typically associated with OFV infection (Chang et al. 1976). Unfortunately, Ko et al. (1985) made no mention of mites or further investigations of this virus. The first certain report of OFV was from Hawaii in 2001 (Blanchfield et al. 2001), while the first report from the continental US was by Bratsch et al. (2015). In that publication, the authors confirmed the presence of OFV in *Phalaenopsis* hybrids in the US, using TEM of ultrathin sections of plant tissue as well as molecular sequence analysis and its association with *Brevipalpus* mites (Bratsch et al. 2015). The authors did not make a conclusive species identification but suggested the mite vector belonged to the *B. californicus* group, as referred by Kondo et al. (2003).

OFV has been reported in other Nolinoidaea in Australia (Mei et al. 2016, Dietzgen et al. 2018b), including *Liriope spicata* (Thunb.) Lour. (Mei et al. 2016) but has not been reported in any of these plants in the US. The *Liriope muscari* cv ‘Gigantea’ is considered a synonym of *Liriope gigantea* Hume (Wang et al. 2014, Masiero et al. 2020), but some consider it a separate species (Fantz et al. 2015). We are not aware of any previous report of OFV-Orc infection in *Ophiopogon* plants. Zheng et al. (2013) does mention an association between *B. californicus* and *A. elatior*, but they never reported symptoms of OFV-Orc in this plant. However, we believe that our findings indicate the first report of OFV-Orc infecting ornamentals in Florida, and possibly the US. This publication also marks the first reports of *A. elatior* and *Ophopogon* spp. as natural hosts of OFV-Orc.

### Conclusion

The dichorhavirus that infects citrus in Hawaii, Mexico, Colombia, and South Africa are identical to the OFV in gene order, content, and the genome sequence. According to the International Committee on Taxonomy of Viruses (ICTV) classification, OFV consist of two orchid strains (OFV-Orc1 and OFV-Orc2) and two citrus strains (OFV-Cit1 and OFV-Cit2). Both the orchid strains of OFV infects citrus (Roy et al. 2020), but none of the citrus strains have been reported from any orchid species. Detecting OFV in Florida represents a concern for horticulturists who grow orchids, *Liriope*, *Ophiopogon*, or other susceptible Asparagaceae species which are commonly used in landscaping. Florida is also home to a plethora of native and naturalized orchid species, many of which are threatened, including cultivating *Vanilla* in southern Florida (Chambers et al. 2019) and the famous Ghost Orchid, [*Dendrophylax lindenii* (Lindl.) Benth. ex Rolfe]. Citrus leprosis was present in Florida during the 1860’s and eradicated in the mid-1960s. In fact, Kitajima et al. (2011) found that the Citrus Leprosis virus (CiLV) which previously affected Florida citrus was a nuclear type of citrus leprosis closely related to OFV strains (Hartung et al. 2015, Roy et al. 2020). Association of a distant relative of OFV named Citrus leprosis dichorhavirus-N0 (CiLV-N0) was confirmed in relation to the leprosis disease outbreak in Florida (Hartung et al. 2015). The recent detection of OFV-Orc1 in South Africa (Cook et al. 2019) in *C. sinensis* (Navel and Valencia orange) and OFV-Orc2 in Hawaii (Velarde et al. 2021) in *C. reticulata* (mandarin) and *C. jambhiri* (rough lemon) associated with leprosis-like symptoms highlights the threat of different strains of OFV on citrus; which will be a definite concern to the US multi-billion dollar citrus industry. *B. californicus*, as well as *B. yothersi* (Baker), are both known vectors of Dichorhaviruses (OFV) (Kondo et al. 2003, Beltran-Beltran et al. 2020) and *B. obovatus* is a suspected vector as well (Childers et al. 2003). All three mite species/complexes are present in Florida (Childers et al. 2003, Akyazi et al. 2017) (Fig. 4), and are difficult to identify by non-experts, or without advanced methodologies. DNA barcoding (**Armstrong2005?**) or a similarly simple and accurate method for identification of these mite complexes is vital to determine which of these species are responsible for transmission of OFV-Orc, and therefore which mite populations need to be monitored or controlled. By doing so, we can determine the risk they represent for the native plants, agriculture and the ornamental/landscaping industries of Florida and the surrounding regions.

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### Table 1: List of Asparagaceae (Nolinoidaea) species with verified cases of *Orchid fleck dichorhavirus*, collected from the landscape of northern Florida

|  |  |  |  |
| --- | --- | --- | --- |
| Scientific Name | Common Names | County | Strains |
| *Liriope muscari* cv. ‘Gigantea’\* (Decaisne) Bailey | Lilyturf, Orchardgrass, Monkeygrass | Alachua & Leon | OFV-Orc1 & OFV-Orc2 |
| *Ophiopogon intermedius*\*\* Don | Aztec Grass, ‘Argenteomarginatus’ | Leon | OFV-Orc1 & OFV-Orc2 |
| *Aspidistra elatior* Blume | Cast Iron Plant, Bar-room Plant | Leon | OFV-Orc1 & OFV-Orc2 |

Table 1: \* *Liriope muscari* cv. ‘Gigantea’ has been traditionally classified as *L. gigantea* Hume by Broussard (2007) and Fantz et al. (2015), although this distinction has been challenged by Wang et al. (2014) and Masiero et al. (2020). \* \* *O. intermedius* is sometimes misclassified as *Liriope muscari* ‘Variegated Evergreen Giant’ Fantz (2009) or ‘Grandiflora White’ (Fantz 2009).

### Figure captions

Fig. 1: Variety of symptoms expressed by *Liriope* spp. infected with Orchid fleck dichorhavirus (OFV): (a) ringspot symptoms on *Liriope gigantea* (b-c) Details of ringspot symptoms on *Liriope gigantea* (d) chlorotic ringspot *Liriope muscari* cv. ‘Silvery Sunproof’

Fig. 2: Symptoms expressed by *Aspidistra elatior* infected with Orchid fleck dichorhavirus (OFV): (a) Detail of leaf chlorosis (b) Chlorosis caused by OFV appears similar to sunburn damage (c-d) Chlorotic ringspot may indicate early symptoms of OFV

Fig. 3: Cryo-SEM images of *Brevipalpus californicus* sensu lato displaying various characters used for identification (Baker and Tuttle 1987, Beard et al. 2012) (a) Dorsum (b) Lateral view (c) Venter (d) Close up of distal end of leg 2, with arrows indicating paired solenidia, characteristic of the genus *Brevipalpus* (e) Enlargement of the microplates of the mite cerotegument (f) Dorsal view of the distal portion of mite abdomen (g) Dorsal view of the mite rostrum (h) Ventral view of mite rostrum, observe 3 distal setae.

Fig. 4: Florida is home to other common pest species of *Brevipalpus*, which are potential vectors of *Orchid fleck dichorhavirus*: (a) *B. phoenicis*, dorsal (b) *B. yothersi*, lateral (c) *B. obovatus*, dorsal.

### Figures







