Monitoring of *Fusarium circinatum* spore loads in South African forest seedling nurseries

by

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DECLARATION

I, Lisa-Danélle de Wet declare that the dissertation, which I hereby submit for the degree *Magister Scientiae* at the University of Pretoria, is my own work and has not previously submitted by me for a degree at this or any other tertiary institution.

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Signature

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PREFACE

Fusarium circinatum is an important pathogen since it is a pathogen of pine trees worldwide, causing extensive destruction of both native pine forests and non-native plantations. The severity of the pitch canker disease caused by this fungus justifies understanding its distribution and spread better. The techniques used for *Fusarium* identification and detection are numerous, however, the quantification techniques for this genus, in particular *F. circinatum*, are limited. The main goal of this study was to detect and quantify the pine pathogen *F. circinatum*, using the intergenic spacer (IGS) region as a diagnostic marker.

Techniques used for the identification of *Fusarium* species can be divided into two groups i.e. non-DNA-based and DNA-based methods. The first chapter reviews the most popular and widely used techniques for *Fusarium* identification. Each group of techniques have similar advantages and disadvantages, although the groups of techniques are better suited to different types of questions and methodologies. Many years ago before the advent of molecular biology, non-DNA-based techniques, based on the morphology of an isolate, were popular. At present DNA-based techniques are more popular as these methods can be automated and considers a species on its most basic level, i.e., its DNA blueprint. DNA-based techniques are, however, usually combined with techniques based on morphology for control purposes and the various techniques also complement each other.

Many specific *F. circinatum* primers have been designed targeting the IGS region, due to this region's fast evolution. The IGS region is evaluated as a diagnostic marker in the second chapter to determine whether this region is indeed a good diagnostic marker. The specificity of the *F. circinatum* specific primers targeting the IGS were compared with the species for comparison including *F. circinatum* and other *Fusarium* species belonging to the *Gibberella fujikuroi* complex. The results indicate that the IGS region is a reliable diagnostic marker as a large part of this region is species-specific. Phylogenetic analysis of the IGS region showed that the isolates group together similarly to the groupings of previous studies that included the same isolates.

The dispersal of *F. circinatum* spores is mostly responsible for the spreading of the pitch canker disease between different individual pines. The disease is found in the whole life cycle of the pine tree, including the seed, seedling and adult stage. A technique to detect *F. circinatum* and quantify the spores can assist in the management of the disease in plantations and seedling nurseries. In chapter three real-time PCR is the chosen technique for detection and quantification of *F. circinatum* spores in a seedling nursery as the success of this technique has been demonstrated in similar studies in the past. Four DNA extraction (from the spores) methods were also compared to increase the effectiveness and sensitivity of the whole detection and quantification process. Over a 12-month period temperature readings were recorded to determine whether there was a correlation between climate and spore production. The spore traps were also placed at different levels to determine whether air movement has an effect on spore dispersal. It was found that some of the DNA extraction methods are better than others, real-time PCR can detect low spore concentrations and temperature has an effect on spore production. This study has proven the effective use of real-time PCR for the detection and quantification of *F. circinatum* spores in a pine seedling nursery.

CHAPTER 1

LITERATURE REVIEW:

TECHNIQUES TO IDENTIFY *FUSARIUM* SPECIES

Abstract: Correct identification of *Fusarium* species, especially those harmful to humans, animals and plants will always be important. Only a few decades ago, the number of identification techniques for these fungi was limited due to technological and knowledge limitations. Since the discovery of the structure of DNA by Watson and Crick in 1953 and the improvement of associated technologies, the number of identification techniques available for fungi has increased remarkably. Originally, the only method to identify and study these fungi was that involving morphological features of isolates. This approach continues to be used, but usually in conjunction with other identification techniques. During the last decade, DNA-based identification techniques have become increasingly valuable as a result of being amenable to automation and the resolving power they provide. This review examines *Fusarium* identification techniques, discussing the properties of each technique, as well as their advantages and limitations. The final section considers the need and value of a polyphasic approach to *Fusarium* identification.

INTRODUCTION

Fusarium resides in the Order Hypocreales and in the Phylum Ascomycota (Seifert and Lévesque, 2004; Hibbett *et al.* 2007; Kristensen *et al.,* 2007b). Knowledge of this genus goes back as far as 1842, when *Fusarium solani* was first described as *Fusisporium solani* (Snyder and Hansen, 1941). *Fusarium* species are widely distributed across the globe where they commonly occur as saprobes or pathogens of higher eukaryotes (Leslie and Summerell, 2006). As plant pathogens, *Fusarium* species are frequently associated with a wide variety of hosts, including cereals and vegetable crops, as well as fruit and tree species (Leslie and Summerell, 2006). As human and animal pathogens, members of this genus are often linked with a range of opportunistic infections (Nelson *et al*., 1994). *Fusarium* species are also abundant in the soil where they form an important component of microbial communities (Nelson *et al.,* 1994). In addition, *Fusarium* species are capable of producing a variety of toxic secondary metabolites or mycotoxins, which have been implicated in numerous animal and human diseases (Nelson *et al.,* 1994; Desjardins, 2003;). The agricultural, medical and veterinary importance of *Fusarium* species, therefore, makes their early detection and correct identification crucially important for effective control and/or management.

An important consideration for the identification process of any fungi is the application of an appropriate Species Concept (Mayden, 1997). The Species Concept determines which experimental approaches or techniques should be used during the identification process, and also how the results of these experiments should be interpreted. Of the numerous Species Concepts available (reviewed by Mayden, 1997), the Morphological, Biological and Phylogenetic Species Concepts (MSC, BSC and PSC, respectively) are most widely used in *Fusarium* taxonomy (Leslie and Summerell, 2006).

Of the three Species Concepts, the MSC is the most extensively used technique, with the description of most *Fusarium* species including morphological diagnoses for differentiation and identification. However, *Fusarium* species are generally associated with a limited number of unique morphological traits (Leslie *et al.,* 2001), which drastically reduces the value of the MSC in *Fusarium* species diagnostics. The BSC concentrates on whether two isolates are capable of crossing sexually to produce fertile progeny (Dobzhansky 1935; Mayr 1996). However, the BSC also has limited application, as it is restricted to sexual species. The third Species Concept, PSC, forms part of most contemporary *Fusarium* classifications and identifications, because it focuses on the lineage of a species, its history (ancestors), future (descendants) and its evolution (how it originated) (Avise and Wollenberg, 1997). A number of excellent reviews on the Species Concepts used for *Fusarium* have been published (e.g., Nelson *et al.,* 1994; Leslie *et al.,* 2001; Summerell *et al.,* 2003; Leslie and Summerell 2006) and the details will not be discussed further in this review.

A second important aspect of the identification process that requires attention is the actual techniques used to diagnose a species. Most modern diagnostic procedures are based on DNA sequence information, although so-called "molecular methods" are sometimes used in conjunction with morphology. These techniques may vary greatly with regards to technical difficulty, financial considerations, time and level of resolution. However, for the purposes of routine species diagnostics, an effective identification technique should be rapid, economical, and quantitative, as well as allowing for direct sample analysis, minimum sample preparation and automation (Nie *et al.,* 2007). In this literature review, methods that have been or are currently used to identify species or strains of *Fusarium* are considered. Their value and suitability for routine diagnostic purposes is also discussed.

MORPHOLOGY AND OTHER CULTURAL TRAITS

Before 1935, hundreds of *Fusarium* species had been described as every isolate that was discovered on a new host was reported to be a new species (Leslie *et al.,* 2001). More order in the identification and classification of *Fusarium* species was introduced by Wollenweber and Reinking (1935). The principles introduced at that time are still the foundation of modern *Fusarium* taxonomy. They divided the approximately thousand *Fusarium* species into sixteen sections, sixty-five species and seventy-five varieties (Wollenweber and Reinking, 1935; Nelson *et al.,* 1994). Snyder and Hansen (1956) concluded that there were only nine *Fusarium* species, but modern taxonomic treatments have shown that this is far from true (Leslie *et al.,* 2001; Seifert and Lévesque, 2004). Booth (1971) produced a synoptic key for the identification of *Fusarium* species based on many of the principles of Wollenweber and Reinking (Leslie *et al.,* 2001). Later, Gerlach and Nirenberg (1982) and Nelson *et al.* (1983) considered the work of Wollenweber and Reinking (Wollenweber and Reinking, 1935), Snyder and Hansen (Snyder and Hansen, 1940) and Booth (Booth, 1971) in order to develop strategies for the identification of *Fusarium* species based on morphological characteristics (Leslie *et al.,* 2001; Summerell *et al.,* 2003; Seifert and Lévesque, 2004). Many of these identification procedures are still widely used today.

A variety of nutrient media are used during the *Fusarium* identification process based on species morphology. The most important are carnation leaf agar (CLA) (Fischer *et al.,* 1982; Nelson *et al.,* 1994; Summerell *et al.,* 2003), potato dextrose agar (PDA), peptone-pentachloronitrobenzene (PPA; also known as *Fusarium* selective medium) (Summerell *et al.,* 2003) and synthetic low nutrient agar (SNA) (Nirenberg and O'Donnell, 1998; Summerell *et al.,* 2003). Isolates grown on CLA are more inclined to sporulate and instead of producing mycelial growth. Isolates produce macroconidia and chlamydospores making this medium valuable because both structures are important for identification under the microscope (Fischer *et al.,* 1982; Nelson *et al.,* 1994; Nirenberg and O'Donnell, 1998). PDA is a nutrient-rich medium that encourages mycelial growth causing isolates to produce colony pigmentation that is useful in identification (Nelson *et al.,* 1994; Summerell *et al.,* 2003). On the other hand, SNA is a low nutrient medium that can maintain strains for long periods of time and encourages the production of microconidia that can be used for identification when visualised under a microscope (Nirenberg and O'Donnell, 1998; Summerell *et al.,* 2003).

A pictorial guide (Summerell *et al.,* 2003) can be used to help with identification according to different spore types and the dimensions of spores, as these characteristics can be unique to a species. Other important characteristics include colony morphology and hyphal growth (Nelson *et al.,* 1994; Summerell *et al.,* 2003). However, a common problem with morphological identification of *Fusarium* species is that different species may have similar or identical morphological characteristics. These are especially well documented for plant pathogenic species such as those in the *Gibberella zeae* (Burgess *et al.,* 1994), *G. fujikuroi* (Kvas *et al.,* 2009) and *F. solani* (Matuo and Snyder, 1972) species complexes.

HOST ASSOCIATIONS

Fusarium species are associated with many plant species and often cause serious diseases (Summerell *et al.,* 2003). As pathogens, they are also capable of infecting different parts of a plant (Summerell *et al.,* 2003). Because of the possible economic losses that may be associated with *Fusarium* diseases of plants, correct species identification is essential for the establishment of appropriate management strategies. This is because identification of the *Fusarium* species found on a specific plant host is important to determine the possible outcome of the disease, assessing and predicting the extent of the damage and whether the *Fusarium* species are in fact the cause of the disease.

Many *Fusarium* species are host-specific. Thus, the host on which an isolate of *Fusarium* is found may represent an important diagnostic character. *F. oxysporum* is a species that cause disease (commonly vascular wilt syndrome) in many different hosts including banana, cotton, legumes and vegetables all of which are economically important crops. *F. oxysporum* strains that cause vascular wilt syndrome are often host specific, infecting only a limited number of hosts. These strains are termed formae speciales as they are divided on a subspecies level, *F. oxysporum* f. sp. *cubense* infecting banana, *F. oxysporum* f. sp. *vasinfectum* infecting cotton and *F. oxysporum* f. sp. *lycopersici* infecting tomato to name a few (Summerell, *et al.* 2003). *F. solani* is another species than contain strains that are host specific (Summerell, *et al.* 2003). Therefore, pathogenicity tests are typically conducted to verify the correct identification and to determine whether a fungus is able to infect a plant and would thus be recognised as the causal agent of a disease.

The steps followed in pathogenicity tests are based on Koch's postulates (Koch, 1891; Fredricks and Relman, 1996; Grimes, 2006). According to these postulates, a pathogen must always be present during disease, the suspected pathogen must be isolated from the diseased host and cultured, a healthy host inoculated with the pathogen must show signs of disease with symptoms identical to the original host's symptoms and it should be possible to isolate the pathogen from the newly diseased host.

When testing for *Fusarium* host associations, the first step is the isolation of the possible pathogen and preparation of pure cultures on isolation medium. These cultures are then used to produce inoculum, which may be in various forms, including spore suspensions (e.g., Benyon *et al.,* 1996; Amatulli *et al.,* 2010) and mycelium obtained from growth media (Pérez-Sierra, 2007). The inoculum is then applied to healthy plants, for example, to the roots (e.g., Cafri *et al.,* 2005), kernels (e.g., Yates and Sparks, 2008) or stems (e.g., Catti *et al.,* 2007). The presence or absence of symptoms identical to those of the original host's symptoms is recorded to determine whether the organism in question is the causal agent of disease (Cafri *et al.,* 2005; Catti *et al.,* 2007; Jacobs *et al.,* 2007; Yates and Sparks, 2008). Finally, the pathogen is isolated from the diseased tissue to show that it was the causal agent of the observed symptoms.

SEXUAL COMPATIBILITY

The most important advantage of evaluating sexual compatibility is that it allows direct testing of the BSC (Dobzhansky, 1935; Mayr, 1996). If two individuals are capable of interacting sexually to produce fertile offspring, they probably represent members of the same species. The major disadvantages associated with this approach for *Fusarium* identifications pertain to issues surrounding asexuality and infertility. The teleomorph form of many species has never been found and most *Fusarium* species are known only in their asexual or anamorph forms. This, in turn, may be because the species is truly asexual, having lost its sexual phase as has been suggested for *F. oxysporum* (Leslie and Summerell, 2006). Alternatively, the inability to detect the sexual stage may be due to the inclusion of isolates in the test that are not sufficiently fertile under suitable laboratory conditions (for example Covert *et al*., 1999) or due to the test being conducted at unsuitable laboratory conditions. Also, many isolates of *Fusarium* are known to have lost their female-fertility (the ability to act as female and produce the progeny bearing fruiting structure) and can only act as males (nuclear donors) in sexual crosses (Leslie and Summerell, 2006). Therefore, "negative results" (failure to induce sexual reproduction and the formation of mature fruiting structures and progeny) do not necessarily indicate that the interacting individuals belong to separate species. The latter is also true for "positive results" (successful induction of sexual reproduction and the formation of fruiting structures that bear fertile progeny), as closely related species may be able to mate (Dobzhansky, 1935; Mayr, 1996). Indeed, the genus *Fusarium* includes numerous examples of such cross-species or hybrid encounters, for example *F. circinatum* and *F. subglutinans* (Steenkamp *et al.,* 2000), and *F. proliferatum* and *F. fujikuroi* (Leslie *et al*., 2004).

Among the sexual species in *Fusarium* (those that have teleomorphs in the genera *Gibberella* and *Haemanectria*), some groups are heterothallic, while others are homothallic (Leslie and Summerell, 2006). Heterothallic species require the interaction of two fertile isolates of opposite mating types to induce the formation of sexual structures and to produce fertile progeny (Leslie and Summerell, 2006). Well-known examples of heterothallic species include those in the *G. fujikuroi* complex. On the other hand, the individuals of a homothallic species can produce sexual fruiting structures bearing fertile progeny, alone, but this form of reproduction results in progeny that are largely clones of the parent (Leslie and Summerell, 2006). Certain species of *Haemanectria* and species in the *G. zeae* complex have this form of sexual reproduction (Hornok *et al*., 2007).

The sexual species in *Fusarium* are generally dimictic, where sexual reproduction is determined by two alleles found at one mating type or MAT locus (Leslie and Summerell, 2006). The two alleles share little sequence similarity and were accordingly designated as the *MAT-1* and *MAT-2* idiomorphs (Cooke, 1958; Kerényi *et al.,* 1999). It has also been shown that the overall structure of this locus in asexual *Fusarium* species resembles that of sexual species (Yun *et al.,* 2000). The only difference between heterothallic and homothallic species, is that the two idiomorph alleles are located adjacent to one another on the same DNA molecule at the MAT locus of the homothallic *Fusarium* species studied to date, while the MAT locus of heterothallic species harbours only one of the idiomorph alleles (reviewed by Leslie and Summerell, 2006). Therefore, by exploiting the sequences at this locus in heterothallic species, it was possible to develop PCR-based approaches for determining the mating type of a specific isolate (Steenkamp *et al.,* 2000; Wallace and Covert, 2000; Yun *et al.,* 2000).

In the laboratory, sexual crosses with *Fusarium* species typically involve culturing the female strains on a medium such as V8 or carrot agar (Britz *et al.,* 1999; Covert *et al.,* 2007) and the male strains on a medium that allows abundant vegetative growth and sporulation (e.g. complete medium or PDA) (Britz *et al.,* 1999; Kerényi *et al.,* 1999; Leslie and Summerell, 2006; Covert *et al.,* 2007). Spores are then harvested from the male parent and used to "spermatise" the female culture. The fertilised cultures are then incubated for several months and regularly examined for the presence of perithecia and ascospores. To verify progeny viability, ascospores may be germinated on water agar, after which the resulting cultures should display growth typical of the parental strains. Ideally, the progeny should also be subjected to sexual crosses to verify that they are indeed fertile. Such viable and fertile progeny generally result only from an interaction between conspecific, sexually compatible parents (Britz *et al.,* 1999; Kerényi *et al.,* 1999; Leslie and Summerell, 2006; Covert *et al.,* 2007).

The widespread occurrence of homothallism in *Fusarium* species complicates the use of sexual compatibility assays to test the BSC (Leslie and Summerell, 2006). This is because these fungi are able to complete the sexual cycle by themselves without the need for an interacting partner (Covert *et al.,* 2007; Hornok *et al.,* 2007), although mating between two isolates (outcrossing) is also possible (Bowden and Leslie, 1999; Hornok *et al.,* 2007). It is therefore, possible to use sexual compatibility tests effectively and where suitable controls are used and the results are interpreted appropriately. For example, to ensure that the emergence of sexual fruiting structures is due to an interaction between mated individuals and not the result of self-fertilisation, the progeny may be examined for the presence of recombinants (Covert *et al.,* 2007). If they display the characters or carry the alleles of only one of the parents, that parent probably gave rise to them through homothallic recombination. If they display traits or carry alleles of both parents, the parents are likely to be conspecific because they both participated in the cross. In addition, improved efficiency of sexual compatibility tests with homothallic species (increased appearance of heterozygous fruiting structures) can be achieved by using female fertile tester strains in which one of the two idiomorph alleles has been inactivated (Leslie and Summerell, 2006).

VEGETATIVE COMPATIBILITY

Vegetative compatibility is typically used to study the population biology of fungal species because this trait is determined by multiple genes or genetic loci (Leslie, 1993). Fungal species are thought to have between ten and fifteen of these loci (reviewed by Leslie and Summerell, 2006). For individuals to be compatible (the hyphae of two individuals fuse to form a stable heterokaryon), they must have similar alleles at all of these loci. Dissimilarity at a single locus usually results in incompatibility, as a stable heterokaryon is not maintained (Leslie, 1993). Due to the multigenic basis of this phenomenon, the progeny of a sexual cross will very rarely be compatible with the parental strains. Therefore, for a fungal species believed to primarily undergo asexual reproduction, vegetative compatibility tests represent a powerful identification technique (Leslie and Summerell, 2006). This is because the lack of meiosis and sexual recombination precludes reshuffling of allelic combinations underpinning a specific vegetative compatibility group. As a result, vegetative compatibility groups form an integral part of the diagnostic procedure for species such as *F. oxysporum* (Puhalla, 1985).

To determine the vegetative compatibility group of an isolate, two isolates are paired and if their hyphae are able to fuse, the isolates are defined as belonging to the same vegetative compatibility group or as vegetatively compatible (Leslie, 1993). This test is facilitated by the use of nitrate non-utilising (*nit*) mutants and pairing of compatible mutants (Correll *et al*., 1987; Klittich and Leslie, 1988). If wild type growth is produced in the area of contact between the two isolates, a stable heterokaryon is formed, which indicates that the paired isolates belong to the same vegetative compatibility group. If no growth is produced in the area of contact between the two isolates and a stable heterokaryon are not formed, the two isolates are vegetatively incompatible (Correll *et al*., 1987; Klittich and Leslie, 1988).

METHODS BASED ON CHEMICAL TRAITS

Chemotaxonomy focuses on the molecules produced by a fungal species and includes the analysis of fatty acids, proteins, secondary metabolites (SMs) and carbohydrates (Frisvad *et al.,* 2008). Chemotaxonomy refers to the use of these chemical compound characteristics for classification or identification purposes (Frisvad *et al*., 2007; Frisvad *et al.,* 2008). To identify a species based on these properties, a profile for the specific compound in a particular isolate is determined and compared to the profiles of known species in a database. The accuracy of identifications is thus dependant on the species-richness of the reference database, which also represents one of the major limitations associated with using chemotaxonomic approaches for species diagnoses. In addition, identification can be complicated by the ability of some species that are not closely related, producing similar compounds (De Nijs *et al*., 1997). Other complications may include individuals that are not equally capable of producing the full range of compounds associated with that particular species (De Nijs *et al*., 1997). Another factor that should also be considered is that the growth phase of the isolate may have an effect on the compounds produced. During sporulation certain secondary metabolites are produced that are not produced during other growth phases (Frisvad *et al.,* 2008).

Despite the various shortcomings associated with chemical compound profiling and chemotaxonomic analysis, these approaches are generally easy to standardise for application in routine identification (De Nijs *et al*., 1997). They are usually not time-consuming or laborious, although they may be dependent on the use of specialised equipment, which could limit their use for diagnostic purposes. In contrast, methodologies that involve more complex biochemical procedures (e.g., isozyme analysis; see below) or that require specialised material (e.g., antibodies used in ELISA; see below) are of limited use for routine diagnostic purposes. In fact, DNA-based procedures have now largely replaced the use of both ELISA and isozyme analyses for identification procedures.

Secondary metabolite profiling

Secondary metabolic compounds (SM) are not essential under normal growth circumstances (Frisvad *et al.,* 2008). They may, however, become necessary under abnormal circumstances, including a change in food sources available and in the presence of predators/competitors (Frisvad *et al.,* 2008). Secondary metabolites, most commonly produced by fungi, which are used for identification include terpenes, polyketides and non-ribosomal peptides (Jegorov *et al.,* 2006; Frisvad *et al.,* 2008). It is widely believed that SMs can be used for the classification and identification of fungi due to their inconsistent distribution in the fungal kingdom (De Nijs *et al.,* 1997; Frisvad *et al.,* 2008).

Mycotoxins represent an important group of SMs in fungi and *Fusarium* in particular. Knowledge of toxins produced on plants dates back to ancient Egypt as recorded in the Dead Sea Scrolls, but mycotoxins were only recognised as associated with plants in the 1900s (Richard, 2007). Mycotoxins commonly appear in the food chain, either directly through the consumption of contaminated food crops, or indirectly when livestock ingest affected feed. Secondary metabolites or mycotoxins of *Fusarium* are almost always associated with severe human and animal diseases (Nelson *et al.,* 1994; Desjardins 2003; Richard, 2007), which further emphasises the need for accurate species diagnosis (Richard, 2007).

Secondary metabolite profiles usually differ between fungal species, because every species produces a unique combination or quantity of small organic compounds most of which are secondary metabolites (Frisvad *et al.,* 2007; Frisvad *et al.,* 2008). Although analyses of all these compounds produced by a species may harbour taxonomically useful information (Frisvad *et al.,* 2008), the association of SMs (mycotoxins in particular) with human and animal disease has emphasised the use of SM profiles for the identification of fungal species in the medical and veterinary environments. *Fusarium* species are known to produce a large range of SMs and mycotoxins such as trichothecenes, fumonisin, moniliformin, zearalenones and enniatins (Kristensen *et al.,* 2007a). Examples of *Fusarium* species that have been differentiated based on SM profiles include *F. culmorum* and *F. avenaceum* (De Nijs *et al.,* 1997), as well as *F. langsethiae*, *F. poae*, *F. sporotrichioides* and *F. kyushuense* (Thrane *et al*., 2004).

To determine the SM profile of an isolate or species, the presence of toxins, antibiotics and other outwardly directed compounds produced during fungal growth under specific conditions are studied (Fischer *et al*., 2000). For this purpose, isolates are typically grown on complex media that are rich in glucose and sucrose, as well as minerals and trace elements (Fischer *et al*., 2000), for example PDA (Frisvad *et al.,* 2008), malt extract agar (MEA) (Fischer *et al*., 2000; Frisvad *et al.,* 2008) and yeast extract-sucrose agar (YES) (Fischer *et al*., 2000; Frisvad *et al.,* 2008). The chemical characteristics of the isolate may then be determined using one of three widely used techniques: chemical spot test, paper chromatography or thin layer chromatography (Frisvad *et al.,* 2008). Although thin layer chromatography is still used as a precursor technique during screening, high-pressure liquid chromatography diode array detection mass spectroscopy (hplc-dad-ms) is currently the technique of choice for fungal chemotaxonomy (Frisvad *et al.,* 2008).

Fatty acid methyl ester analysis

Fatty acid methyl ester (FAME) analysis is a chemotaxonomic technique that concentrates on the quantity and type of fatty acids produced by a fungus (Aye *et al.,* 2008). To achieve identification, the fatty acids are extracted from an isolate and separated by gas chromatography. FAME analysis allows identification to genus, species or strain levels (Aye *et al.,* 2008). However, when it was applied to the fungi associated with rice blight, the method did not allow for differentiation between *F. roseum* and *F. solani*, although it did differentiate the *Fusarium* species from *Rhizopus* and *Pythium* species (Aye *et al.,* 2008).

Infrared spectroscopy of cellular constituents

Fourier transform infrared spectroscopy determines the presence or absence of functional groups that may be unique to an isolate by irradiating the isolate with infrared light at different wavelengths (McMurry, 1998; Kos *et al*., 2002; Nie *et al.,* 2007). Infrared spectroscopic techniques that have been used in the past to detect fungi include photoacoustic spectroscopy (PAS), diffuse reflectance spectroscopy (DRS) and attenuated total reflectance spectroscopy (ATR) (Kos *et al.*, 2002). Infrared spectroscopy is based on the fact that different molecules absorb electromagnetic energy differently, which may be reflected in the potential energy curves of the molecules caused by the interaction of the molecules with infrared radiant energy (McMurry, 1998; Illingworth and Cullerne, 2000). Thus, during electromagnetic radiation, an exposed organic compound absorbs energy of certain wavelengths, which allows the generation of an absorption spectrum for the compound at various irradiation wavelengths. This is accomplished by using the Fourier transform mathematical algorithm, which allows the conversion of the raw absorbance data into the specific spectrum (*i.e.*, the absorbance units are functionally expressed and possibly related to wave numbers that are also functionally expressed) (Illingworth and Cullerne, 2000). A number of studies have used the Fourier transform infrared spectroscopy technique successfully to identify *F. graminearum*, *F. moniliforme*, *F. nivale*, *F. oxysporum* and *F. semitectum* (Kos *et al.*, 2002; Nie *et al.,* 2007).

Isozyme analyses

The protein constituents of an unknown species may be examined for identification purposes. Isozyme analysis represents an example of such a protein-based method that has been widely used in fungal (Micales *et al.,* 1986), and especially *Fusarium* taxonomy (Huss *et al.,* 1996; Yli-Mattila *et al.,* 1996; Abd-Elaah, 1998; Mohammadi *et al.,* 2004). The method exploits the fact that different species generally produce unique combinations of isozymes (Mohammadi, *et al.,* 2004). To evaluate this, the isozymes produced by a sample/isolate are extracted and separated by polyacrylamide gel electrophoresis. The isozyme bands are then visualised with appropriate stains and enzyme-buffer systems (Huss *et al.,* 1996; Yli-Mattila *et al.,* 1996; Mohammadi *et al.,* 2004). Isozyme profiles are then compared to a reference database to allow identification of the unknown sample/isolate.

ELISA-based methods

Enzyme-Linked Immunosorbent Assay (ELISA) may be used to detect a particular microbial species within a specific sample. ELISA is based on the detection of surface antigens or secreted antigens by an antibody with a detectable enzyme linked to the antibody (McCartney *et al.,* 2003; Jegorov *et al.,* 2006). Polyclonal antibodies (Aldwell *et al.*, 1983; Kaufman *et al.,* 1997; Ward *et al.,* 2004), monoclonal antibodies (Park *et al.,* 2003; Ward *et al.,* 2004; Hill *et al.*, 2006) and antibodies produced by phage display (Ward *et al.,* 2004) are the three types of antibodies that can be used for identification and detection. Antigens can be detected by direct detection (Ward *et al.,* 2004; Hill *et al.,* 2006), indirect detection (Aldwell *et al.,* 1983; Ward *et al.,* 2004) or by "sandwich" detection where antibodies attach to two sides of the antigen (Ward *et al.,* 2004). A basic ELISA technique for detecting and quantifying *Fusarium* species found on barley was developed (Hill *et al*., 2006) and used to study the fungi associated with *Fusarium* Head Blight (FHB) (Hill *et al.,* 2008). As with the use of other cellular constituents for the identification of species, the main limitation of ELISA is the availability of reference information, in this case appropriate antibodies to allow accurate identifications.

DNA-BASED IDENTIFICATION TECHNIQUES

Identification methods based on DNA information can generally be separated into two main groups, those that result in fingerprints, and those that access the sequence information directly. These two groups of methods differ in terms of their applicability for routine species identification. Fingerprinting methods, for example, suffer from the same limitations as those associated with chemical compound profiles (see above), as any particular DNA fingerprint must be compared to a database of reference fingerprints for known species. Thus, where the database is limited or if the unknown sample is new to Science, positive identifications are impossible. Also, with DNA-fingerprinting the possibility of homoplasy cannot be excluded, because a specific band in a fingerprint of two species is not necessarily underpinned by orthologous DNA information (Yli-Mattila *et al*., 1996). Methods that are based on the actual DNA information are much more powerful in this regard, because species are usually distinguishable based on the uniqueness of their particular DNA sequence. In the following sections, the various DNA-based approaches used for the identification of fungi and *Fusarium* species, in particular, are briefly discussed.

DNA-fingerprinting methods

Restriction fragment length polymorphism (RFLP)

The first DNA-based method that was widely applied in fungal taxonomic studies was restriction fragment length polymorphism (RFLP). For this method, genomic DNA is digested with endonucleases, separated by electrophoresis and polymorphisms visualised following Southern hybridization with specific probes (Niesters *et al.,* 1993; Barve *et al.,* 2001). Because this method is tedious and labour-intensive, it now has limited application for the identification of *Fusarium* species. Instead, a variant of the RFLP technique, PCR-RFLP, is used much more often for taxonomic purposes. PCR-RFLP entails the amplification of a specific genomic region using PCR, followed by digestion of the amplicon with restriction endonucleases and visualisation of the polymorphisms with standard gel electrophoresis procedures (Paavanen-Huhtala *et al.,* 1999; Kim *et al.,* 2001; Hinojo *et al.,* 2004; Llorens *et al.,* 2006a). Because of the simplicity and robustness of PCR-RFLPs, the approach has been used widely for the identification of *Fusarium* species (Young-Mi *et al.,* 2000; Konstantinova and Yli-Mattila, 2004) such as those in the *G. fujukuroi* complex (Hinojo *et al*., 2004) and *F. redolens* (Bogale *et al.,* 2007), as well as formae speciales of *F. oxysporum* (Manicom *et al*., 1986; Appel and Gordon, 1995).

Random amplified polymorphic DNA (RAPD)

RAPD is a PCR-based method in which single, short oligonucleotide primers are used to amplify arbitrary genomic regions, followed by visualisation of polymorphisms with standard gel electrophoresis methodologies (Williams *et al.,* 1990). RAPD techniques have been used extensively for the identification of *Fusarium* species such as *F. oxysporum,* in particular (Chiocchetti *et al.,* 1999; Paavanen-Huhtala *et al.,* 1999; Del Mar Jiménez *et al.,* 2001; El-Fadly *et al.,* 2008). However, the RAPD technique is notoriously sensitive, which limits its reproducibility within and among laboratories (Vos *et al.,* 1995). As a result, contemporary *Fusarium* identification procedures seldom use this method.

Amplified fragment length polymorphisms (AFLPs)

AFLPs harness the best qualities of genomic RFLPs and RAPDs to produce a simple and robust DNA fingerprinting method (Vos *et al*., 1995). In principle, restricted genomic DNA fragments are ligated to adaptors (with known sequences) and amplified, to allow the amplification of fingerprints, which are visualised with standard electrophoresis methods (Vos *et al.,* 1995; Blears *et al.,* 1998). Since its introduction, AFLP has been applied for taxonomic purposes in many fungi (Abdel-Satar *et al.,* 2003). In fact, *Fusarium* isolates of a single species have been shown to display AFLP fingerprints that share 70 % or more similarity (Summerell *et al*., 2003). This method has been used to study *Fusarium* species such as *F. langsethiae* (Schmidt *et al.,* 2004), *F. avenaceum*, *F. chylamdiosporum, F. oxysporum*, *F. moniliforme* and *F. solani* (Abdel-Satar *et al.,* 2003).

Denaturing gradient gel electrophoresis (DGGE)

DGGE is a popular technique for microbial ecology, as it solves the problem associated with most DNA-fingerprinting techniques of being unable to separate non-identical DNA fragments of the same size (Muyzer and Smalla, 1998). This is because these fragments are each characterised by their own denaturation properties. Thus, by applying such fragments to DGGE analysis (which uses polyacrylamide gel electrophoresis and a DNA denaturant such as urea and formamide with a linear gradient), it should be possible to separate such non-identical fragments from one another. These products can then be visualised with an appropriate DNA stain, and each band of an individual fingerprint will represent a unique sequence type (Muyzer and Smalla, 1998). To obtain identifications, these individual fragments are compared to the DGGE fragments of known references species, or individual fragments can be sequenced directly to allow putative identification. Because this method allows for a culture-independent examination of the species potentially present in a particular environment, DGGE is gaining in popularity (Theelen *et al*., 2001; Mach *et al.,* 2004). In the case of *Fusarium* it has, for example, been used to address ecological questions pertaining to Asparagus (*Asparagus officinalis*) root and crown rot (Yergeau *et al.,* 2005).

DNA sequence analysis of specific genomic regions

The utilisation of DNA sequence information for species identification typically involves phylogenetic tree-based and non-tree-based analyses. For tree-based identifications, DNA sequence information for the test isolates is subjected to phylogenetic analyses, after which conclusions regarding species identities are made from phylogenetic trees (Felsenstein, 1981). This approach is widely used in *Fusarium* taxonomy where it has allowed the systematic analysis of species in the *G. fujikuroi* (O'Donnell *et al*., 1997; O'Donnell *et al.,* 2000), *G. zeae* (O'Donnell *et al.,* 2004b) and *F. oxysporum* (O'Donnell *et al*., 2004a) complexes.

DNA sequence information-based identifications that are dependent on non-tree-based analysis procedures typically involve the calculation of sequences similarities. This can, for example, be achieved by making use of BLAST (Basic Local Alignment Search Tool; http://www.ncbi.nlm.nih.gov) and public domain databases such as the nucleotide database (GenBank) of the National Center for Biotechnology Information (http://www.ncbi. nlm.nih.gov). The detection of specific single nucleotide polymorphisms (SNPs) (Rafalski, 2002; Kristensen *et al.,* 2007a) can also be used (Rafalski, 2002).

Sequence analysis of housekeeping loci

Markers commonly used for *Fusarium* diagnostics and identification include the genes encoding β-tubulin, histone H3, translation elongation factor 1 alpha (TEF) and the ribosomal RNA (rRNA) subunits (O'Donnell and Cigelnik, 1997; O'Donnell *et al.,* 1998; Geiser *et al*., 2004), as well as the rRNA intergenic spacer (IGS) region (Kim *et al*., 2001). In fact, comparisons have shown that phylogenetic trees inferred from the mitochondrial small subunit (mtSSU) rDNA, the nuclear 28S rDNA, β-tubulin and TEF are congruent (O'Donnell and Cigelnik, 1997; O'Donnell *et al*., 1998). The only exception is in the rRNA internal transcribed spacer 2 (ITS2), which appears to have non-orthologous origins (O'Donnell and Cigelnik, 1997). The ITS regions are, therefore, not used for *Fusarium* identifications. This is despite the fact that the ITS region is the preferred DNA barcoding region for fungi (Pryce, *et al*., 2003). Instead, the TEF region has been proposed for use in routine identifications of *Fusarium*, as this gene region appears to evolve sufficiently fast (harbours enough variation to allow species differentiation) and it does not harbour non-orthologous copies (Geiser *et al*., 2004).

Species-specific PCR primers or probes

Species-specific PCR primers and probes have been developed by making use of diagnostic motifs occurring in specific genes or regions (e.g., IGS, β-tubulin, TEF, and mating type genes) (McCartney *et al.,* 2003; Ma and Michailides, 2007). They can also be developed by making use of the results of DNA fingerprinting studies, where diagnostic RAPD or AFLP fragments are sequenced and further characterised by determining the sequence of up- and downstream regions (McCartney *et al.,* 2003; Ma and Michailides, 2007). For *Fusarium* species, various species-specific primer sets or probes are available and are most commonly based on the sequence information for the rRNA IGS (Jurado *et al.,* 2005) and the genes encoding Tox5 (Demeke *et al.,* 2005) and 28S rDNA (Edel *et al.,* 2000).

To increase the speed and efficiency of species identification with species-specific PCR primers and probes, electrochemiluminescence PCR (Wei and Zhou, 2008), indirect real-time PCR (Ioos *et al*., 2009) and direct real-time PCR (Schweigkofler *et al*., 2004; Garbelotto *et al.,* 2008) have been used. For electrochemiluminescence PCR, each primer has a universal fragment attached to its tail, resulting in the amplicons containing known sequences. After PCR, hybridisation of two probes (biotin labelled probe and TBR labelled probe) complimentary to the universal/known sequences occurs followed by capturing by magnetic beads. During the capturing process, biotin and streptavidin interact and are detected by electrochemiluminescence. This technique is sensitive, simple and specific (Wei and Zhou, 2008). It has been used to detect *Fusarium* wilts caused by *F. oxysporum* f.sp. *cubense* (Wei and Zhou, 2008).

During indirect real-time PCR, fluorescence is generated during primer extension of the amplification stage of PCR, using the hydrolysis probe system (Leišova *et al.,* 2006). The hydrolysis probe is digested by the 5' activity of DNA polymerase causing a fluorescence quencher and reporter to become separated, resulting in the emission of light (the quencher cannot quench the fluorescence if not in close proximity to the reporter). During direct real-time PCR, a fluorescent molecule binds to, or is incorporated into, the amplification product, the result being the emission of light (Walker, 2001). In both direct and indirect real-time PCR, fluorescence or the emission of light reveals that the DNA for the target species is included in the sample mixture.

Examples of both types of real-time PCR are available for the pine pitch canker pathogen, *F. circinatum*. Indirect real-time PCR was used to detect this fungus in pine seeds by using a dual-labelled probe unique to *F. circinatum*'s IGS (Ioos *et al*., 2009). For detection and quantification of this fungus with direct real-time PCR, species-specific primers, are used to amplify a portion of the IGS in the presence of the fluorescence dye SYBR Green (Schweigkofler *et al*., 2004; Garbelotto *et al.,* 2008).

Microsatellites

Microsatellites are short tandem repeats, usually 1-10 bp long, that differ in length between isolates due to their high mutation rate (Jarne and Lagoda, 1996; Powell *et al.,* 1996). Sequences adjacent to the microsatellites are used to produce primers that allow the amplification of the microsatellites with PCR, after which the amplicons are separated on a gel by electrophoresis to reveal polymorphisms (Longato and Bonfante, 1997; Barve *et al.,* 2001; Santana *et al.,* 2009). Although microsatellites are usually used for population genetic studies, they are also useful for identifying the formae speciales and races of *F. oxysporum* (Barve *et al.,* 2001).

Microarrays

For large-scale identification of specific groups of fungi such as *Fusarium*, microarray technology has been used. Microarrays are based on the hybridisation of two complementary sequences, during which a known DNA sequence fragment of an organism is attached to a solid support, usually a glass slide (Wilson *et al.,* 2002; Spiess *et al.,* 2007) or silica chip (Campa *et al.,* 2008). The target genomic region is then amplified with PCR from the unknown isolates, labelled, denatured and hybridised to the DNA on the slide. Following wash steps to remove the unbound DNA, hybridisation is detected by the emittance of fluorescent light (Wilson *et al.,* 2002; Yoo *et al.,* 2009). This technology is commonly used for the diagnosis and identification of human fungal pathogens (Spiess *et al.,* 2007; Campa *et al.,* 2008) but also for the diagnosis and identification of *Fusarium* plant pathogens and those that produce mycotoxins in grain crops (Nicolaisen *et al.,* 2005; Kristensen *et al.,* 2007b).

THE NEED FOR POLYPHASIC METHODS IN *FUSARIUM* DIAGNOSTICS

Polyphasic identification involves the characterisation of a species at many levels, including the genotypic, phenotypic and phylogenetic characteristics of an organism (Vandamme *et al.,* 1996). The reason this approach has grown in popularity is that different techniques complement each other, where the one technique overcomes the shortcomings of others and vice versa. *Fusarium* identification could thus include DNA-based, as well as information regarding morphology, host, etc. (Llorens *et al.,* 2006b).

For *Fusarium* species, the polyphasic approach is also expanded to the actual Species Concept used. Morphological characteristics that are often used during application of the Morphological Species Concept (MSC) for identifying *Fusarium* species are limited in number and are often affected by environmental conditions, possibly resulting in a change in these characteristics (Leslie *et al.,* 2001). As discussed previously, the Biological Species Concept (BSC) can also not be used to identify all *Fusarium* species. Although application of the Phylogenetic Species Concept (PSC) generally overcomes problems associated with the other identification criteria, it may complicate identifications in the absence of additional data. Therefore, the PSC is typically used in conjunction with the MSC and/or the BSC.

CONCLUSIONS

Most *Fusarium* identification techniques have their own set of advantages and disadvantages. Advantages include specificity, sensitivity, speed, ease of automation and low cost. Disadvantages include labour intensity, high level of expertise needed, time needed, high costs and unreliability. DNA-based techniques have received the most attention in recent years as they can be automated and consider a species at its most basic level, its genetic sequence. This is also seen in the range of DNA-based methods used for the identification of *Fusarium* species. I think the technique that warrants more attention is microarrays as it allows for the identification of large numbers of isolates and species simultaneously. However, improvements in next generation sequencing technologies (Mardis, 2008; Morozova and Marra, 2008; Schuster, 2008) should make high- throughput sequence analysis for large-scale species identifications also feasible in the near future.

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CHAPTER 2

EVALUATION OF THE INTERGENIC SPACER (IGS) REGION AS A DIAGNOSTIC MARKER FOR *FUSARIUM CIRCINATUM*

Abstract: The pathogen *Fusarium circinatum*, causal agent of pitch canker in pine (*Pinus* spp.) is a threat to both native pine forests and non-native plantations worldwide. The dissemination of the pathogen is believed to be facilitated by various factors including wind, water splash, insect vectors and silvicultural practices. Effective monitoring and detection of the pathogen is thus important for disease management. Although a variety of DNA markers are commonly used for *Fusarium* diagnostics, markers based on the ribosomal RNA intergenic spacer (IGS) are used most frequently for identification and quantification of the pitch canker fungus. The aim of this study was to evaluate the suitability of the IGS region as a diagnostic marker for identifying *F. circinatum*. For this purpose, the IGS region was sequenced and the various primer and probe target areas were compared among different isolates of the fungus. The *F. circinatum* sequences were also compared to those obtained for other *Fusarium* species. These included species that are known to occur in the same environment as *F. circinatum* (e.g., *F. oxysporum*, *F. proliferatum*), as well as species that are closely related to this fungus (e.g., *F. subglutinans*). Phylogenetic analysis revealed three distinct clades for the *Gibberella fujikuroi* complex. Single nucleotide polymorphisms (SNPs) and indels were present within the IGS region of *F. circinatum* and the other *Fusarium* species included in this study. It was, however, found that none of the polymorphisms had a significant effect on the *F. circinatum* target sites. The IGS region is, therefore, valuable not only for diagnostics but also for population studies as this region has polymorphisms that are significant at an intraspecies level.

INTRODUCTION

Pitch canker of pine is caused by the ascomycete fungus, *Fusarium circinatum* (Schweigkofler *et al.,* 2004; European and Mediterranean Plant Protection Organization, 2005) that was first described in 1946 in the southern United States (Hepting and Roth, 1946). Since then the pathogen has been reported from various pine growing regions around the world (Wikler and Gordon, 2000; Ramsfield *et al.,* 2008) where it affects a large number of *Pinus* species (EPPO, 2005; Wingfield *et al.,* 2008) and *Pseudotsuga menziesii* (Wingfield *et al.,* 2008; Ioos *et al.,* 2009). The pathogen is thought to spread via the movement of untreated wood, wood products, infected seedlings, and contaminated growth medium (Mireku and Simpson, 2002; Wingfield *et al.,* 2008), as well as pine-associated insects such as *Rhyacionia* spp. (Matthews, 1962; Runion and Bruck, 1985), *Contarina* sp. (Dwinell *et al.,* 1985) and *Brachyderes incanus* (Romón *et al.,* 2007) to name a few. Globally, *F. circinatum* is regarded as one of the most important pathogens of *Pinus* species and has been associated with great economic losses due to seedling and tree mortality, as well as reduction in wood quality and production (Mireku and Simpson, 2002; Wingfield *et al.,* 2008).

The pitch canker pathogen was initially thought to represent a *forma specialis* of *Fusarium subglutinans* because of its resemblance to this fungus and its specific association with *Pinus* species (Britz *et al.,* 2001; Wingfield *et al.,* 2008). *Fusarium subglutinans* f. sp. *pini* was later elevated to species level and named *F. circinatum* (teleomorph = *Gibberella circinata*) (Britz *et al.,* 2001; Wingfield *et al.,* 2008), which forms part of the *G. fujikuroi* species complex (Nirenberg and O'Donnell, 1998; Britz *et al.,* 1999) belonging to mating population H (Britz *et al.,* 1999; Desjardins, 2003). The most important culture-based identification methods for *F. circinatum* include morphology (Nirenberg and O'Donnell, 1998) and sexual compatibility tests (Britz *et al.,* 1998; Britz *et al.,* 2005). However, such culture-based identification procedures are time-consuming and can lead to ambiguous identifications as different *Fusarium* species may have similar morphological characteristics (Matuo and Snyder, 1972; Burgess *et al.,* 1994; Kvas *et al.,* 2009). Consequently, all diagnoses of the pitch canker pathogen now include some sort of DNA-based procedure, as these allow for much more rapid and robust identifications.

The markers most commonly used for the diagnosis of *F. circinatum* and other *Fusarium* species include regions of protein-coding genes such as β-tubulin (O'Donnell *et al.,* 2000), histone H3 (Steenkamp *et al.,* 1999), and translation elongation factor 1-alpha (TEF) (Geiser *et al.,* 2004). Although the ribosomal RNA (rRNA) genes and spacer regions have been used to some extent for studying certain *Fusarium* species (Gaudet *et al.,* 1989; Peterson and Logrieco, 1991), their conserved (Ganley and Kobayashi, 2007) and non-orthologous nature (O'Donnell and Cigelnik, 1997) generally preclude applications in diagnostics, especially for species in the *G. fujikuroi* complex. In contrast the rRNA intergenic spacer (IGS) apparently contains various regions with species-specific polymorphisms that allow the separation of some *Fusarium* species (Kim *et al.,* 2001; Ganley and Kobayashi, 2007).

Currently, there are three DNA-based strategies available for identifying an isolate as *F. circinatum*. TEF-barcode analysis involves sequencing of a specific portion of the TEF gene and comparisons against a database of voucher sequences (Geiser *et al.,* 2004). The H3 PCR-RFLP method uses restriction endonucleases for targeting *F. circinatum*-specific polymorphisms in the histone *H3* gene (Steenkamp *et al.,* 1999; Schweigkofler *et al.,* 2004).

The third approach involves the application of *F. circinatum*-specific real-time PCR primers (Schweigkofler *et al.,* 2004; Ramsfield *et al.,* 2008; Ioos *et al.,* 2009). The latter approach has the advantages of being more sensitive and specific than conventional PCR and allows for quantification of *F. circinatum* DNA in the sample (McCartney *et al.,* 2003; Ioos *et al.,* 2009). Three sets of species-specific PCR primers are available for the pathogen (Schweigkofler *et al.,* 2004; Ramsfield *et al.,* 2008; Ioos *et al.,* 2009), of which two sets (Schweigkofler *et al.,* 2004; Ioos *et al.,* 2009) specifically target the rRNA IGS.

The multicopy nature of the IGS region makes it valuable in diagnostics. All eukaryotic genomes, including that of *F. circinatum*, harbour numerous copies (sometimes thousands) of rRNA repeat regions (Rooney and Ward, 2005; Ganley and Kobayashi, 2007) arranged head-to-tail and separated by non-coding spacers (ITS and IGS) (Kim *et al.,* 2001) (Figure 1). The sequences of these repeats are kept intact through the processes of homogenisation (Peterson and Logrieco, 1991; Simon and Weiβ, 2008) and gene conversion (Peterson and Logrieco, 1991; Jeffreys and May, 2004). In general the functional rRNA gene regions tend to have limited sequence variation due to selective constraints (Boffelli *et al.,* 2004), while spacers (containing promoter and non-coding regions) are apparently more tolerant to substitutions and indels (insertions and deletions) (Britten *et al.,* 2003; Mak *et al.,* 2006; Ganley and Kobayashi, 2007). Therefore, the IGS appears to be the fastest evolving non-coding rRNA region (Kim *et al.*, 2001) resulting in this region being more variable between different species than other regions of the rRNA (Fernández *et al.,* 2000; Kim *et al.,* 2001; Llorens *et al.,* 2006; Ganley and Kobayashi, 2007).

The objective of this study was to evaluate the suitability of the rRNA IGS region as a diagnostic marker for *F. circinatum*. For this purpose, comparisons of the complete sequence of the IGS region for the various biological species in the *G. fujikuroi* complex were used. The information obtained will enable the design of *F. circinatum* specific primers and/or probes to be used in future as a routine diagnostic procedure for the detection and monitoring of the pitch canker pathogen in a specific environment.

MATERIALS AND METHODS

Fungal isolates

The strains used in this study included *F. circinatum* isolates from different geographical regions to ensure that the various species-specific primers/probes are indeed specific to this species irrespective of an isolate's origin (Table 1). *Fusarium oxysporum*, *F. proliferatum* and *F. subglutinans* (Table 1) isolates were also included as *F. oxysporum* and *F. proliferatum* are commonly found in pine nurseries and *F. subglutinans* is closely related to *F. circinatum*.

DNA extraction, PCR and sequencing

All isolates were subcultured on potato dextrose agar (PDA) (Merck, Wadeville, Gauteng) at 25 °C for 7 days. Genomic DNA was isolated from the individual *Fusarium* isolates by making use of an extraction method based on CTAB (N-Cetyl-N,N,N-Trimethyl ammonium bromide) (Merck) (O'Donnell and Cigelnik, 1997). The complete *F. circinatum* IGS region was amplified in three overlapping regions (Figure 1) with primers GCNS7r (5' GTTGTTAAGAGGCGCGGTGTC 3'), GCNS3 (5' CTGCAAAGCTGTACAGAGGG 3') (Figure 1), CIRC4A (5' ACCTACCCTACACCTCTCACT 3') (Schweigkofler *et al.,* 2004) and FCIR-F (5' TCGATGTGTCGTCTCTGGAC 3') (Ioos *et al.,* 2009). For *F. oxysporum*, *F. proliferatum* and *F. subglutinans,* the total IGS region was amplified in two overlapping regions with primers GCNS7r (5' GTTGTTAAGAGGCGCGGTGTC 3'), GCNS3 (5' CTGCAAAGCTGTACAGAGGG 3') (Figure 1), NL11 (5' CGTAACGCCTCTAAGTCAG 3') (Figure 1) and CNS1 (5' GAGACAAGCATATGACTAC 3') (Figure 1) (Schweigkofler *et al.,* 2004).

Each 25-µl PCR mixture contained *ca.* 1 ng template DNA, 0.63 mM $MgCl_2$ (Roche, Germany), 0.25 mM dNTPs (Fermentas, Vilnius, Lithuania), 0.25 µM of each primer (Inqaba Biotech, South Africa), 1.25 U/µl *Taq* DNA polymerase (Roche, Germany) and reaction buffer (FABI, Pretoria, South Africa). All PCRs were conducted on a BioRad iCycler (Hercules, California, USA). The cycling parameters were similar to those used by Schweigkofler *et al.* (2004) and were as follows: 94 °C for 90 s, 40 cycles of 94 °C for 30 s, 52 °C for 30 s and 68 °C for 3 min, followed by 68 °C for 5 min and 4 °C until removed. The presence of PCR products was verified by gel electrophoresis. The resulting PCR products were then purified with G50 Sephadex columns (Sigma, Steinheim, Germany) and sequenced by making use of an ABI PRISM BigDye v3.0 Cycle Sequencing Kit (Applied Biosystems, Foster City, California) and a 3730 DNA Analyser (Applied Biosystems, Foster City, California). Raw sequence data were visualized and corrected where necessary with Chromas Lite version 2.01 (Technelysium Pty. Ltd.) and BioEdit version 7.0.5.3 (Hall, 1999).

IGS sequence analysis

The full-length IGS sequences of all the isolates were aligned using the web-based alignment tool MAFFT (multiple sequence alignment based on the fast Fourier transform) version 6 with the L-INS-I (iterative refinement method using local pairwise alignment with affine gap cost) (Katoh, *et al.* 2002; http://align.bmr.kyushu-u.ac.jp/mafft/online/server/) function. BioEdit was used to identify and compare within this alignment, the various sequences for PCR primers, *F. circinatum*-specific primers CIRC1A (5' CTTGGCTCGAGAAGGG 3'), CIRC4A (5' ACCTACCCTACACCTCTCACT 3') (Schweigkofler *et al.,* 2004), FCIR-F (5' TCGATGTGTCGTCTCTGGAC 3') and FCIR-R (5' CGATCCTCAAATCGACCAAGA 3') (Ioos *et al.,* 2009) and probe FCIR-P (5' CGAGTCTGGCGGGACTTTGTGC 3') (Ioos *et al.,* 2009).

The IGS alignment was extended to include the IGS sequences for species in the *Gibberella fujikuroi* complex that were included in the Schweigkofler *et al.* (2004) study. These sequences were obtained from the *Fusarium* database (http://fusarium.cbio.psu.edu, and included *F. anthophilum* NRRL 13602, *F. bactridioides* NRRL 20476, *F. begoniae* NRRL 25300, *F. bulbicola* NRRL 13618, *F. circinatum* NRRL 25331, *F. concentricum* NRRL 25303, *F. fractiflexum* NRRL 28852, *F. fujikuroi* NRRL 13566, *F. globosum* NRRL 26131, *F. oxysporum* NRRL 22902, *F. proliferatum* NRRL 22944, *F. pseudoanthophilum* NRRL 25206, *F. subglutinans* NRRL 22016, *F. succisae* NRRL 13613, *Fusarium* sp. NRRL 25195, *Fusarium* sp. NRRL 25204, *Fusarium* sp. NRRL 25346, *Fusarium* sp. NRRL 25622, *Fusarium* sp. NRRL 25623, *Fusarium* sp. NRRL 25807, *Fusarium* sp. NRRL 26756, *Fusarium* sp. NRRL 26757, *Fusarium* sp. NRRL 29123, *F. thapsinum* NRRL 22045, *F. verticillioides* NRRL 22172). The resulting dataset was subjected to Maximum-likelihood phylogenetic analysis using jModelTest 0.1 (Posada, 2008) and PhyML 3.0 (Guindon and Gascuel, 2003).

RESULTS

The lengths of the PCR amplicons ranged from 450 base pairs (bp) to 970 bp, depending on the primer pair used. Primer pairs NL11 and CNS1 generated fragments with an average length of 970 bp, those produced with GCNS7r and GCNS3 were on average 650 bp in length, and primers FCIR-F and CIRC4A produced fragments of about 750 bp in length. The final IGS sequences produced in this study ranged from 1029 bp in length for *F. subglutinans* (MRC 2802) to 2650 bp for *Fusarium* sp. (NRRL 25623) (see Appendix 1 for an alignment of the complete IGS).

Phylogenetic analysis of the IGS sequences separated the sequences included in this study into three well-supported clades (Figure 2). These clades correspond to the so-called "Asian", "African" and "American" clades of O'Donnell *et al.* (1998). This analysis further revealed that all the *F. circinatum* isolates grouped together within the "American" clade (Figure 2). Within the *F. circinatum* clade there was, however, no apparent grouping of isolates according to their geographic origins. This is because isolates from Florida and South Africa group together and California, Florida, Mexico and Spain group together.

In addition to hundreds of single nucleotide polymorphisms (SNPs), comparison of all the IGS sequences included in this study revealed the presence of several indels ranging in size from 2 bp to 18 bp. The *F. circinatum* isolates harboured seven indels at positions 314-322 bp, 396-397 bp, 405-411 bp, 646-647 bp, 716-724 bp, 1157-1167 bp, 1669-1679 bp. All the *F. oxysporum* isolates had two indels that were between positions 362 and 372 and positions 389 and 399 bp in the alignment. *Fusarium succisae* (NRRL 13613) had an insertion between positions 400 and 408 bp, and a deletion between position 1161 and 1178 bp. Isolate NRRL 25206 (*F. pseudoanthophilum*) had an insertion and a single-base deletion at between positions 489 and 495 bp and at position 733 bp, respectively. Between positions 804 and 811 bp, five isolates [*F. concentricum* (NRRL 25303), *F. fractiflexum* (NRRL 28852), *F. fujikuroi* (NRRL 13566), *F. globosum* (NRRL 26131) and *F. proliferatum* (NRRL 22944)] harboured an insertion. No indels were detected among the remaining nine sequences [*F. begoniae* (NRRL 25300), *F. bulbicola* (NRRL 13618), *Fusarium* sp. (NRRL 25195), *Fusarium* sp. (NRRL 25622), *Fusarium* sp. (NRRL 25623), *Fusarium* sp. (NRRL 25807), *Fusarium* sp. (NRRL 26756), *Fusarium* sp. (NRRL 26757) and *F. verticillioides* (NRRL 22172)].

Upon closer inspection of the *F. circinatum* sequences, it was apparent that no intra-specific polymorphisms severely affected the target sites for the primers and probes examined here. This was the case for the 29 SNPs, as well as the indel (between positions 459 and 518 bp) contained within the sequence of the *F. circinatum* isolate from Spain. The Ioos *et al.* (2009) species-specific primers and probe were identical to IGS sequence motifs of all the *F. circinatum* isolates included in this study. The only exceptions were *F. circinatum* isolate CMW 28961 (that harboured a deletion in part of the target region for FCIR-R) and isolate FCC 2265 that only had 14 out of a total of 21 nucleotides identical to primer FCIR-R (Figure 3). Also, the sequence of FCIR-F was identical to the corresponding region in *F. bactridioides*, *F. begoniae*, *F. bulbicola* and *F. succisae*. The sequence of FCIR-R was identical to the corresponding region in *F. subglutinans* and 18 of its 21 nucleotides matched those in the target region of the *F. anthophilum* IGS. The sequences of the Schweigkofler *et al.* (2004) species-specific primers were identical to the corresponding IGS motifs of all the *F. circinatum* isolates included in this study (Figure 4). However, one *F. subglutinans* isolate (MRC 8553) harboured an IGS sequence motif identical to CIRC1A, and CIRC4A was also identical to the sequences of *F. subglutinans* (MRC 2082) and *F. succisae*.

DISCUSSION

Interspecies variation within the IGS region of *Fusarium* species is common (Appel and Gordon, 1995; Kim *et al.,* 2001; Schweigkofler *et al.,* 2004) and was also observed in this study. The phylogenetic tree, based on the IGS data, resembled the one produced by Schweigkofler *et al.* (2004), which was also similar to those inferred from TEF (Geiser *et al.,* 2005) and β-tubulin (O'Donnell *et al.,* 2000; Geiser *et al.,* 2005) sequences. In all cases, the *Fusarium* isolates that were included were separated into the three expected clades. In cases where there were exceptions (e.g., the position of *F. concentricum*, *F. fractiflexum* and *F. fujikuroi*) the relevant nodes lacked bootstrap-support. However, the IGS phylogeny produced in the present study was markedly different from those that have been previously inferred from rRNA ITS data (O'Donnell *et al.,* 2000). Although some groupings were supported by the IGS and ITS data (e.g. the sistergroup relationship between *F. circinatum* and *F. subglutinans*), they merely reflected the fact that the species in the group harbour orthologous ITS regions (O' Donnell *et al.,* 2000). Therefore, the overall phylogenetic history of the two *G. fujikuroi* complex rRNA regions is not congruent, because the IGS tree is concordant with those inferred from of the commonly used protein-coding genes. The IGS region thus represents an additional and easily exploitable region for phylogenetic studies of *Fusarium* species in this complex.

Significant levels of polymorphism in the IGS were detected at the intraspecies level. This is consistent with what has been found for other species, especially *F. oxysporum* (Appel and Gordon, 1995; Kim *et al.,* 2001). The results presented here, therefore, suggest that, in addition to being useful for species diagnostic purposes, that the IGS region also holds valuable information at the population level.

Another important aspect of this study was to evaluate the specificity of the existing *F. circinatum*-specific primers. The so-called "American" species *F. bactridioides*, *F. begoniae*, *F. bulbicola* and *F. succisae* all had sequences identical to FCIR-F. The same was also true for *F. subglutinans* that had sequences identical to FCIR-R (Ioos *et al.,* 2009). Overall, the *F. circinatum*-specific primers and probes were all complementary to at least one isolate that was not *F. circinatum*, although both primers of a set were never complementary to the target regions in the IGS of one non-*F. circinatum* isolate. It is thus reasonable to expect that the application of these primers and probes will allow for the detection of *F. circinatum* only, although positive diagnoses would have to be verified.

A possible disadvantage of the Schweigkofler *et al.* (2004) method is that it is dependent on the interaction of only two oligonucleotides with the target DNA during PCR. In contrast, the Ioos *et al.* (2009) method requires that two oligonucleotide primers and the oligonucleotide probe interact with the target DNA regions, thus increasing the specificity of the reaction. Also, despite the fact that the CIRC1A and CIRC4A primers were complementary to all the *F. circinatum* isolates, the CIRC1A was identical to one *F. subglutinans* (MRC 8553) isolate and CIR4A to another *F. subglutinans* (MRC 2802) isolate. Although *F. subglutinans* is a pathogen of maize and not expected to be found in the same niche as *F. circinatum*, the possibility exists that *F. subglutinans* may be detected with the *F. circinatum*-specific primers. This is especially true in regions where pine and maize growing areas overlap.

To ensure the specificity of the *F. circinatum* diagnosis, Schweigkofler *et al.* (2004) included in their study additional "American" clade species (*F. anthophilum*, *F. bacteridioides, F. begoniae*, *F. bulbicola*, *F. subglutinans* and *F. succisae*). They found that at an annealing temperature of 66 °C or higher produce the most accurate results because this temperature allows the amplification of a 360 bp fragment from the isolates for *F. circinatum* only. Sub optimum diagnostic PCRs, may therefore yield false positives due to the presence of species in the *G. fujikuroi* complex that belong to the American clade. In such instances, sequencing as an additional step may be a crucial requirement for diagnoses. Alternatively, different combinations of the primers used by Ioos *et al.* (2009) and Schweigkofler *et al.* (2004) could be used or new primers may be developed to prevent the occurrence of false positives during the diagnostics of *F. circinatum*.

DNA-based diagnostics are important in the identification of *F. circinatum*, to overcome the problems associated with culture-based methods. The results of this study demonstrate that the IGS region is an excellent marker for *Fusarium* (including *F. circinatum*) diagnostics due to the fact that it contains numerous polymorphisms, many of which are species-specific. Undoubtedly, methods based on the IGS region will remain essential tools in the routine identification, monitoring and quantification of *F. circinatum* in the commercial forestry environment.

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FIGURES AND TABLES

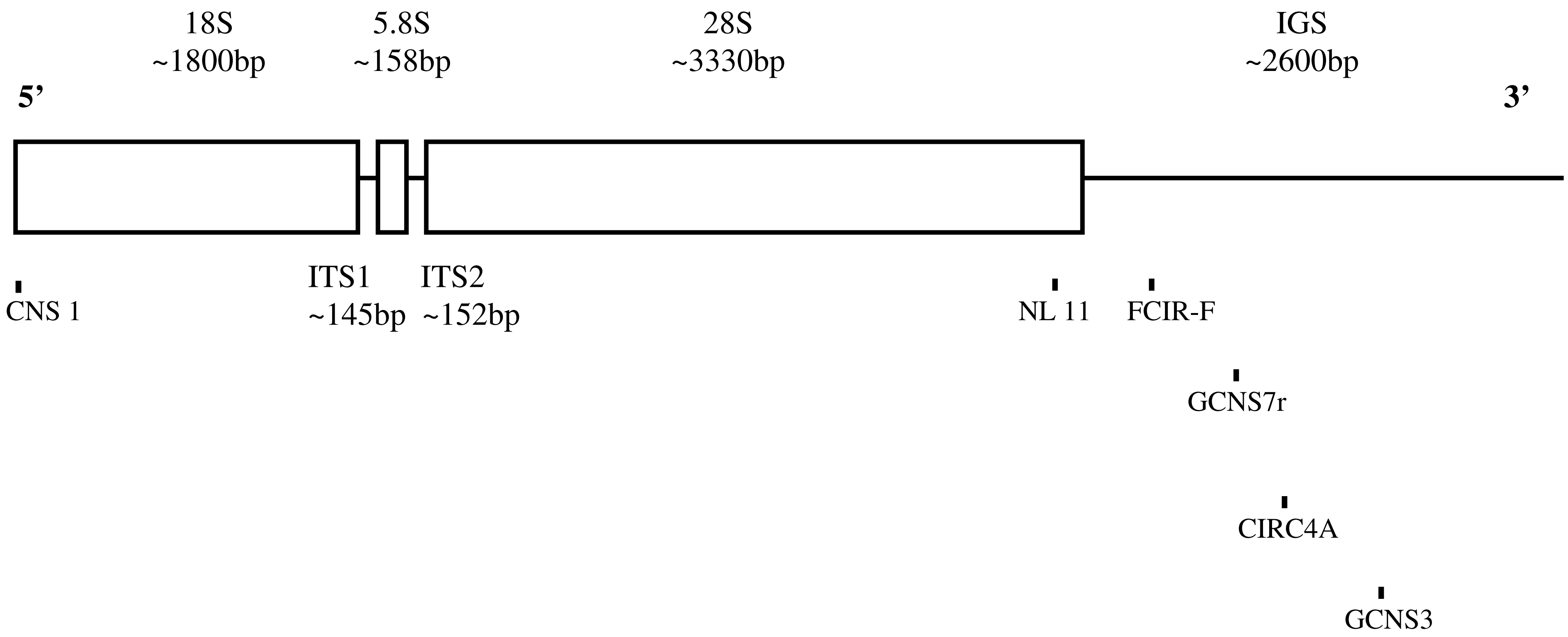

FIGURE 1: Ribosomal RNA region including the non-coding regions (on scale) and the regions where the primers used in this study attach. (Appel and Gordon, 1995; Burton *et al.,* 2005; Kane and Rollinson, 1998; Kim *et al.,* 2001; Lafontaine and Tollervey, 2001)

TABLE 1: *Fusarium* isolates included for IGS region sequences

Isolate	Isolate number	Origin	Collector(s)
F. circinatum	CMW 3198[a]	USA (California)	G. Thomas
F. circinatum	FCC 2472[a]	USA (California)	Unknown
F. circinatum	FCC 2483[a]	USA (Florida)	Unknown
F. circinatum	FCC 2496[a]	USA (Florida)	Unknown
F. circinatum	FCC 2497[a]	USA	Unknown
F. circinatum	FCC 2248[a]	Mexico	Unknown
F. circinatum	FCC 2265[a]	Mexico	Unknown
F. circinatum	CMW 23565[a]	Mexico	Unknown
F. circinatum	FCC 0010[a]	South Africa	Unknown
F. circinatum	FCC 0041[a]	South Africa	Unknown
F. circinatum	FCC 1834[a]	South Africa	G. Hunter
F. circinatum	CMW 28961[a]	Spain	E. Iturritxa
F. oxysporum	CAV 105[a†]	South Africa	A. Viljoen
F. oxysporum	CAV 602[a†]	Australia	Unknown
F. oxysporum	CAV 617/1107 [a†]	Vietnam	I. Buddenhagen, N. Moore, S. Bentley
F. oxysporum	CAV 794[a†]	Indonesia	Unknown
F. oxysporum	CAV 929[a†]	Philippines	L. Magnaye
F. proliferatum	CMW 12864[a]	USA	J. F. Leslie
F. proliferatum	CMW 12867[a]	USA	J. F. Leslie
F. proliferatum	MRC 2301[a]	USA (California)	J. Leslie
F. proliferatum	MRC 8549[a]	USA (California)	Unknown
F. proliferatum	MRC 8550[a]	Unknown	Unknown
F. subglutinans	MRC 8553[a]	Unknown	Unknown
F. subglutinans	MRC 8554[a]	USA (Illinois)	Unknown
F. subglutinans	MRC 6512[a]	USA (Illinois)	J. F. Leslie
F. subglutinans	MRC 2802[a]	South Africa	C. Schreuder

[a]*Fusarium* collection of the Tree Pathology Co-operative Programme (TPCP), Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria, South Africa

[†]Fourie *et al.*, (2009)

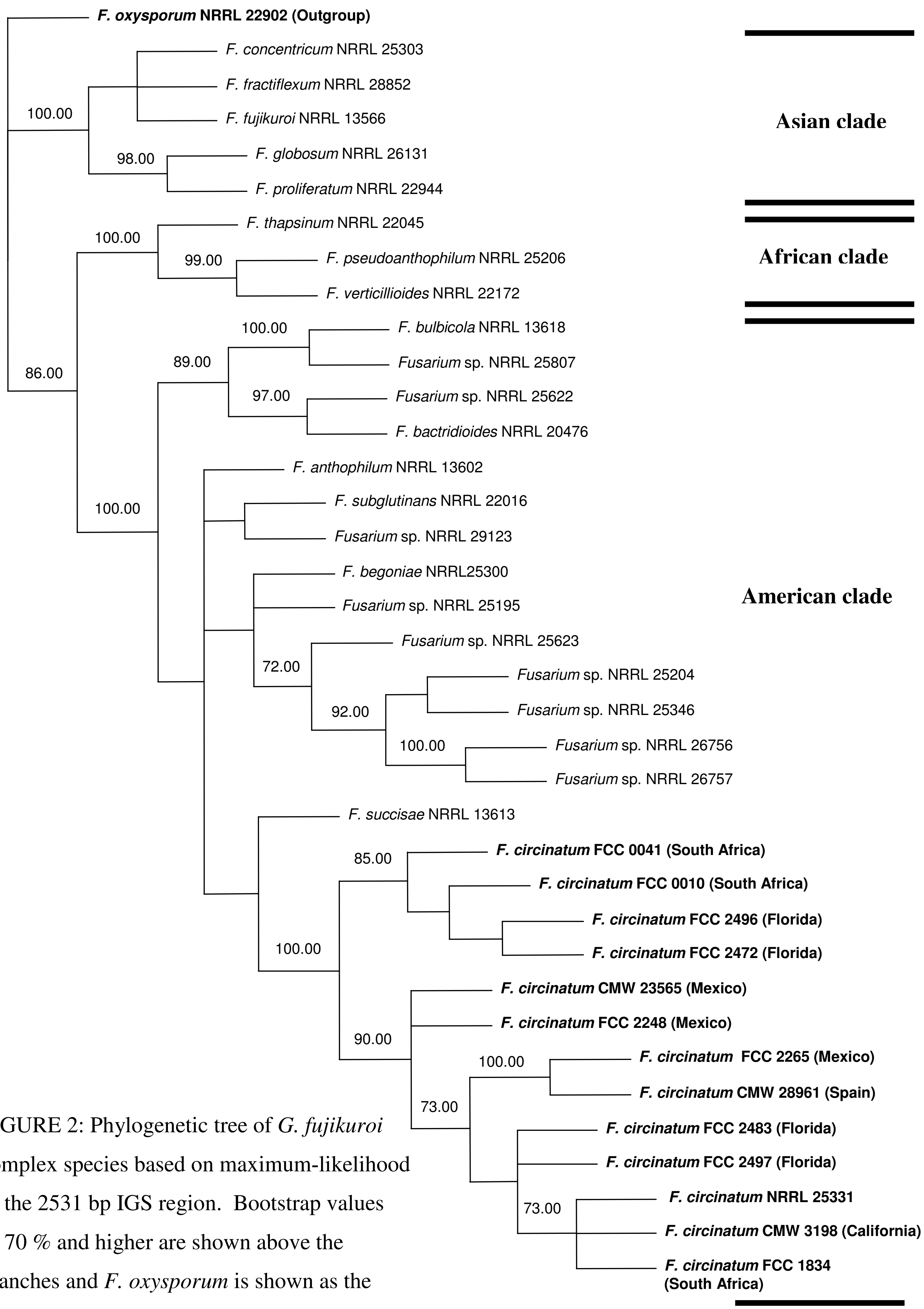

FIGURE 2: Phylogenetic tree of *G. fujikuroi* complex species based on maximum-likelihood of the 2531 bp IGS region. Bootstrap values of 70 % and higher are shown above the branches and *F. oxysporum* is shown as the outgroup.

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                                 302                321     379                 399   446                 466
F. circinatum NRRL 25331         TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum CMW 3198           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 2483           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 2497           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum CMW 23565          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FI 120             TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 0041           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 2248           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 0010           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 2472           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 1834           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. circinatum FCC 2265           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGATTTCATTCCGT
F. circinatum CMW 28961          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGAT----------
F. anthophilum NRRL 13602        TCGA-TGTGTCGTCTCTGGAC-----CGAGCCTGGCAGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. bactridioides NRRL 20476      TCGA-TGTGTCGTCTCTGGAC-----TGAGTCTGGCAGGACTGTGTG-----TCTTGGTCGATTTGGGGAGTG
F. begoniae NRRL 25300           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTTTGTG-----TCTTGGTCGSTTTGAGGATCG
F. bulbicola NRRL 13618          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTGTGTG-----TCTTGGTCGATTCGAGGATCG
F. concentricum NRRL 25303       --GA-TGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATTCGAGGGCTG
F. fractiflexum NRRL 28852       --GA-TGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTCTG-----TCTTGGTCGATTCGAGGATCG
F. fujikuroi NRRL 13566          --GA-TGTGTCGTCTCCGGAC-----CGAGTCTGGCGCGAGTGTGTG-----TGTTGGTCGATTCGAGGATCG
F. globosum NRRL 26131           --GA-TGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATTTGATGATCG
F. oxysporum NRRL 22902          --GA-TGTGTCGTCTCCGGAC-----CGAGTCTGGT----------------ACATGGTCGGTTCGAGGATCG
F. proliferatum NRRL 22944       --GA-TGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATGTGATGATCG
F. pseudoanthophilum NRRL 25206  TCGA-GATGTCGTCTCCGGAC-----CGAGTCTGGCACGATTGTGTG-----TCTTGGTCGATTCAAAGATCG
F. subglutinans NRRL 22016       TCGATTGTGTCGTCTCTGGAC-----CGAGTCTGGCAGCACTCTGTG-----TCTTGGTCGATTTGAGGATCG
F. succisae NRRL 13613           TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCGGGACTTTGTG-----TCTTGGTCGACTTGAGGATCG
Fusarium sp. NRRL 25195          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
Fusarium sp. NRRL 25204          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGGCTTTGTG-----TCTTGGTCGATTCGAGGATCG
Fusarium sp. NRRL 25346          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
Fusarium sp. NRRL 25622          TCGA-TGTGTCGTCTCTGGAC-----TGAGTCTGGCAGGACTGTGTG-----TCTTGGTCGATTTGAGGATCG
Fusarium sp. NRRL 25623          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
Fusarium sp. NRRL 25807          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGATTGTGTA-----TCTTGGTCGATTCGAGGATCG
Fusarium sp. NRRL 26756          TCGA-TGCGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTTTGTG-----TCTTGGTCGATTTAAGGATCG
Fusarium sp. NRRL 26757          TCGA-TGCGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTTTGTG-----TCTTGGTCGATTTAAGGATCG
Fusarium sp. NRRL 29123          TCGA-TGTGTCGTCTCTGGAC-----CGAGTCTGGCAGCACTTTGTG-----TCTTGGTCGATTTGAGGATCG
F. thapsinum NRRL 22045          TCGA-GATGTCTTCTCCGGAC-----CGAGTCTGGCACGATTGTGTG--------------------------
F. verticillioides NRRL 22172    TCGA-GATGTCGTCTCCGGAC-----CGAGTCTGGCACGATTGTGTG-----TCTTGGTCGATTCGAGGATCG
F. oxysporum CAV 105             ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGT----------------ACATGGTCGGTTCGAGGATCG
F. oxysporum CAV 602             ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGT----------------ACATGGTCGGTTCGAGGATCG
F. oxysporum CAV 617             ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGT----------------ACATGGTCGGTTCGAGGATCG
F. oxysporum CAV 794             ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGT----------------ACATGGTCGGTTCGAGGATCG
F. oxysporum CAV 929             C-GATGTGTCGTCTCCGGACC-----GAGTCTGGT-----------------ACATGGTCGGTTCGAGGATCG
F. proliferatum CMW 12864        ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATCTGATGATCG
F. proliferatum CMW 12867        ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATCTGATGATCG
F. proliferatum MRC 8549         ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATCTGATGATC-
F. proliferatum MRC 2301         ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATCTGATGATCG
F. proliferatum MRC 8550         ---GATGTGTCGTCTCCGGAC-----CGAGTCTGGCATGGCTGTGTG-----TCTTGGTCGATCTGATGATCG
F. subglutinans MRC 8553         TCGATTGTGTCGTCTCTGGAC-----CGAGTCTGGCAGCACTCTGTG-----TCTTGGTCGATTTGAGGATCG
F. subglutinans MRC 8554         TCGATTGTGTCGTCTCTGGAC-----CGAGTCTGGCAGCACTCTGTG-----TCTTGGTCGATTTGAGGATCG
F. subglutinans MRC 6512         TCGATTGTGTCGTCTCTGGAC-----CGAGTCTGGCAGCACTCTGTG-----TCTTGGTCGATTTGAGGATCG
F. subglutinans MRC 2802         TC-GATGTGTCGTCTCTGGAC-----CGAGTCTGGCAGGACTTTGTG-----TCTTGGTCGATTTGAGGATCG
FCIR-F                           TCGA-TGTGTCGTCTCTGGAC
FCIR-P                                                     CGAGTCTGGCGGGACTTTGTG
FCIR-R                                                                               TCTTGGTCGATTTGAGGATCG
```

FIGURE 3: *Fusarium* species alignment for the portions of the IGS that harbour the Ioos *et al.* (2009) oligonucleotides. Numbers at top of Figure indicate the position on the IGS; – Indicates sequence gaps or unknown nucleotides.

	1356 1371 1699 1719
F. circinatum NRRL 25331	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum CMW 3198	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 2483	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 2497	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum CMW 23565	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 2496	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 0041	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 2248	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 0010	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 2472	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 1834	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum FCC 2265	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. circinatum CMW 28961	CTTGGCTCGAGAAGGG-----AGTGAGAGGTGTAGGGTAGGT
F. anthophilum NRRL 13602	CTTTGCACGAGAAACG-----AGGTAGTGGTGTAGGGTAGGT
F. bactridioides NRRL 20476	CCTGGCTTGAGAAATG-----AGGTAGTGGTGTAGGGTAGGT
F. begoniae NRRL 25300	CTTTGCACGAGAAACG-----ATGTAGTGGTGTAGGGTAGGT
F. bulbicola NRRL 13618	CTTGGCTCGAGAAACG-----AGGAAGTGGTGTAGGGTAGGT
F. concentricum NRRL 25303	CTTTGCTTGAGAAACG-----TTGATGTGGTATAGGGTAGGT
F. fractiflexum NRRL 28852	CTTTGCTTAAGAAACG-----TTGAAGTGGTATAGGGTAGGT
F. fujikuroi NRRL 13566	CTTTGCTTGAGAAACG-----TTGAAGTGGTATAGGGTAGGT
F. globosum NRRL 26131	CTTTGCTCGAGAAACG-----TTGAAGTGGTATAGGGTAGGT
F. oxysporum NRRL 22902	CTTTAGTCGAGGGAGG-----GTGTGGTGGTGTAGGGTAGGT
F. proliferatum NRRL 22944	CTTTGCTTGAGAAACG-----TTGAGGTGGTATAGGGTAGGT
F. pseudoanthophilum NRRL 25206	CTTGGCTCGAGAAGCG-----ATGCAGAGGTATAGGGTAGGT
F. subglutinans NRRL 22016	CTTGGCTCGAGAAGGG-----GGGGAGAGGTGTAGGGTAGGT
F. succisae NRRL 13613	CTTGGCTCGAGAAACG-----AGTGAGAGGTGTAGGGTAGGT
Fusarium sp. NRRL 25195	CTTTG--CGAGAAACG-----AGGGAGAGGTGTAGGGTAGGT
Fusarium sp. NRRL 25204	CTTTGCACGCGAAACG-----AGGTAGTGGTGTAGGGTAGGT
Fusarium sp. NRRL 25346	CTTTGCACGAGAAACG-----AGGTAGTGGTGTAGGGTAGGT
Fusarium sp. NRRL 25622	CTTGGCTCGAGGAACG-----AGGTAGTGGTGTAGGGTAGGT
Fusarium sp. NRRL 25623	CTTTGCACGAGAAACG-----AGTGAGAGGTGTAGGGTAGGT
Fusarium sp. NRRL 25807	CTTGGCTCGAGAAACG-----AGGTAGTGGTGTAGGGTAGGT
Fusarium sp. NRRL 26756	CTTTGCACAAGAAACG-----AGGGAGTGGTGTAGGGTAGGT
Fusarium sp. NRRL 26757	CTTTGCACAAGAAACG-----AGGGAGTGGTGTAGGGTAGGT
Fusarium sp. NRRL 29123	CTTGGCTCGAGAAACG-----AGGTAGTGGTGTAGGGTAGGT
F. thapsinum NRRL 22045	TTTTGCTCGAGAAACG-----ATGCAGAGGTATAGGGTAGGC
F. verticillioides NRRL 22172	CTTTGCTCGGAAAACG-----GTGTGGAGGTATAGGGTAGGT
F. oxysporum CAV 105	--TTACCCGAGGGAGG-----ATGTGGTGGTGTAGGGTAGGT
F. oxysporum CAV 617	TTTTACTCGAGGGAGG-----ATGTGGTGGTGTAGGGTAGGT
F. oxysporum CAV 794	TTTTACTCGAGGGAGG-----ATGTGGTGGTGTAGGGTAGGT
F. oxysporum CAV 602	TTTTATTCAAGGGAGG-----ATGTGGTGGTGTAGGGTAGGT
F. oxysporum CAV 929	TTTTATTCAAGGAAGG-----ATGTGGTGGTGCAGGGTAGGT
F. proliferatum CMW 12864	TTTTGTTTGAAAAACG-----TTGAGGTGGTATAGGGTAGGT
F. proliferatum MRC 2301	TTTTGTTTGAAAAACG-----TTGAGGTGGTATAGGGTAGGT
F. proliferatum CMW 12867	TTTTGCTTGAAAAACG-----TTGAGGTGGTATAGGGTAGGT
F. proliferatum MRC 8550	TTTTGCTTGAAAAACG-----TTGAGGTGGTATAGGGTAGGT
F. proliferatum MRC 8549	TTTTGCTTGAAAAACG-----TTGAGGTGGTATAGGGTAGGT
F. subglutinans MRC 8553	CTTGGCTCGAGAAGGG-----GGGGAGAGGTGTAGGGTAGGT
F. subglutinans MRC 8554	---------------------GGGGAGAGGTGTAGGGTAGGT
F. subglutinans MRC 6512	CTTGGCTCGAAAAGGG-----GGGGAGAGGTGTAGGGTAGGT
F. subglutinans MRC 2802	CTTTGAAAAAGAAAGG-----AGTGAGAGGTGTAGGGTAGGT
CIRC1A	CTTGGCTCGAGAAGGG
CIRC4A	AGTGAGAGGTGTAGGGTAGGT

FIGURE 4: *Fusarium* species alignment for the positions of the IGS that harbour the Schweigkofler *et al.* (2004) oligonucleotides. Numbers at top of Figure indicate the position on the IGS; – Indicates sequence gaps or unknown nucleotides.

CHAPTER 3

MONITORING SPORE LOADS OF THE PITCH CANKER FUNGUS, *FUSARIUM CIRCINATUM*, IN A PINE SEEDLING NURSERY

Abstract: Detection and quantification are important steps in developing management strategies for pathogens. Many different techniques can be used to quantify the presence and concentrations of viruses, bacteria and fungi. Plant pathogens cause great economic losses, and these include *Fusarium circinatum* that causes a serious canker disease of pines. Two previous studies were conducted that focused on the quantification of *F. circinatum* spores in a native pine forest and one study that focused on the detection of this pathogen on pine seeds. In all three of these studies, real-time PCR was used for quantification or detection. The advantage that real-time PCR offers compared to conventional PCR is that the technique is capable of determining the original amount of DNA for organisms present at the start of the PCR cycle. The quantity can provide an indication of the extent of the infection and the steps that might be appropriate for its management. This study used real-time PCR to determine the spore concentrations of *F. circinatum* in a pine seedling nursery over a 12-month period and considered whether temperature had an effect on the spore concentration. The real-time PCR technique was successful in quantifying spore concentrations and it appears that temperature has an effect on spore concentrations, although the effect was less obvious than expected.

INTRODUCTION

Fusarium circinatum is an important pathogen of *Pinus* species worldwide (Gordon, 2006; Wingfield *et al.,* 2008). This pathogen can infect all parts of the host plant including the main trunk, branches, cones, seeds, and roots (Wingfield *et al.,* 2008). Typical symptoms include branch dieback, development of resinous cankers at the point of infection (Wingfield *et al.,* 2008) and the infection of roots that results in damping-off and root or collar disease (Wingfield *et al.,* 2008).

The dispersal of spores of the pitch canker pathogen is mediated by a variety of factors. These include wind, water splash, insect vectors and transmission through infected seed (Britz *et al.,* 2001; Wingfield *et al.,* 2008). Irresponsible silvicultural and nursery practices can also lead to the introduction of the pathogen into regions that were previously free of pitch canker (Wingfield *et al.,* 2008). Therefore the combination of sterile practises in nurseries, effective quarantine strategies and early identification of the pathogen are important for preventing the dispersal of the pathogen (European and Mediterranean Plant Protection Organization, 2005; Wingfield *et al.,* 2008).

In order to monitor the presence of a pathogen in a specific environment, a variety of detection techniques are available. These include antibody-based techniques (Ward *et al.,* 2004) and various nucleic acid-based techniques (McCartney *et al.,* 2003; Ward *et al.,* 2004,). Of the latter group, real-time PCR methods based on non-specific fluorescent dyes such as SYBR Green and hydrolysis probes using TaqMan technology (Bowyer, 2007) are most commonly used. A typical real-time PCR determines the amount (number of copies) of amplicons after each cycle during PCR measured by fluorescence, which is proportional to the number of amplicons generated (Mackay *et al*., 2002; Bustin, 2005). The cycle where the overall emission of fluorescence shifts from reflecting background noise to that of the actual DNA target is known as the threshold cycle (C_t). By making use of this C_t-value, the original amount of target DNA in the reaction can be determined (Mackay *et al*., 2002; McCartney *et al.,* 2003; Bustin, 2005). Real-time PCR methods thus provide both qualitative and quantitative data and may be used to detect and quantify a pathogen in a specific environment.

Real-time PCR methods for the detection and quantification of pathogens in a specific environment have various advantages. These methods are exceptionally sensitive (Klein, 2002) and they can be conducted relatively rapidly (Burlakoti *et al.,* 2007; Ciglenečki *et al.,* 2008; Bustin *et al.,* 2009). Most importantly, however, real-time PCR methods are not dependent on culturing of the target organism(s) (Nicolaisen *et al.,* 2009), provided that appropriate PCR targets and suitable DNA isolation methods are available. For *Fusarium* species, various DNA targets and DNA isolation methods are available for use in real-time PCR methodologies. Commonly used DNA targets include the ribosomal RNA intergenic spacer (IGS) region (Schweigkofler *et al.,* 2004; Ioos *et al.,* 2009) and the genes encoding *Tri5* (Burlakoti *et al.,* 2007), translation elongation factor 1 α (Nicolaisen *et al.,* 2009) and beta-tubulin (Reischer *et al.,* 2004). Popular DNA isolation methods include those using commercial kits (e.g., GeneClean and Qiagen DNeasy Minikit®) (Wallace and Covert, 2000; Schweigkofler *et al.,* 2004; Ioos *et al.,* 2009; Nicolaisen *et al.,* 2009) and those using surfactants such as hexadecyltrimethylammonium bromide (CTAB) (Lee and Taylor, 1990) and DNA isolation methods based on phenol-chloroform extraction (Atkins and Clark, 2004).

The use of real-time PCR methods based on SYBR Green and other non-specific DNA binding dyes (Bustin, 2005; Heid *et al.,* 2010) has several advantages over those based on hydrolysis probes and TaqMan technology. The most important of these is that SYBR Green-based methods are more flexible and cost effective (Bowyer, 2007). Although hydrolysis probes are more specific because they only bind to target DNA (Sarlin *et al.,* 2006; Burlakoti *et al.,* 2007), these probes are usually expensive to design and produce (Bowyer, 2007). Although, the SYBR Green-based methods do not require these probes (Newby *et al.,* 2003), the use of SYBR Green and similar dyes for detection and quantification purposes are associated with a number of important limitations. For example, non-optimal PCRs may produce primer-dimers with which the non-specific dye will associate, thus resulting in false positives of inaccurate quantifications (Mackay *et al*., 2002). Therefore, optimal PCR and cycling conditions are typically used in combination with melting curve analysis after real-time PCR (Bustin, 2005). The latter allows for differentiation between double stranded DNA of the target amplicons and primers-dimers (Mackay *et al*., 2002; Bowyer, 2007), as primer-dimers are usually associated with lower melting temperatures (Bowyer, 2007; Ciglenečki *et al.,* 2008).

The objective of this study was to develop a cost effective real-time PCR procedure to detect and quantify the spores of *F. circinatum* in the nursery environment. For this purpose, the specific aims were threefold: (i) to evaluate four widely used extraction procedures for their efficiency in isolating good-quality DNA from spores that have been deposited on filter paper traps, (ii) to design a real-time PCR protocol for the routine quantification of *F. circinatum* spores trapped in a pine seedling nursery, and (iii) to use this method to monitor the spore loads in the nursery environment over a 12-month period.

MATERIALS AND METHODS

Experimental pine nursery and spore traps

Two spore trap structures were placed in the experimental greenhouse, one at the front and the other the back of the greenhouse (12 x 15 m) based at the University of Pretoria experimental farm, Forestry and Agricultural Biotechnology Institute (FABI) nursery, Pretoria, South Africa. This greenhouse is used for routine pathogenicity tests with *F. circinatum* to evaluate the susceptibility of different pine species, families and hybrids to pitch canker. For these tests seedlings were inoculated with various strains (FCC 3977, FCC 3978 and FCC 3979), stored in the *Fusarium* collection of the Tree Protection Co-operative Programme (TPCP), at FABI, University of Pretoria, Pretoria, South Africa. Three 70 mm Whatman No.1 filter paper discs (Whatman BioSystems Ltd., Maidstone, Kent, England) were attached to each of the spore trap stuctures at heights of 0.2 m, 0.8 m (tray level) and 2.0 m above ground level. These filter papers served as solid surfaces onto which the aerial spores of the pitch canker pathogen (derived from pathogenicity tests conducted at the time) could be deposited. All six of the spore traps were replaced every two weeks for a total period of 52 weeks by first wetting the filter paper with 4xTE buffer (pH 8; 40 mM Tris HCl, 4 mM EDTA) to increase spore-trapping capability. The minimum and maximum temperatures were recorded every second week.

Preparation of DNA standards

To determine the most efficient DNA isolation procedure and to generate standards for use in the real-time PCR runs, three isolates of *F. circinatum* were used. These were FCC 2254, FCC 2265 and FCC 2472; all obtained from the *Fusarium* collection of the TPCP. Other *Fusarium* species were not included, as the specificity of the CIRC1A and CIRC4A primers were evaluated in Chapter 2 and found to be specific for *F. circinatum*. The *F. circinatum* isolates were inoculated onto ½ strength potato dextrose agar (PDA, Merck, Wadeville, Gauteng) medium. After 7 days of incubation at 25 °C, cultures were flooded with 4 ml of autoclaved distilled water (dH_2O) and swirled to loosen spores. Spores were then quantified using a haemocytometer (Marienfeld, Germany) after which a serial dilution of 10^0 spores/ml, 10^1 spores/ml, 10^2 spores/ml, 10^3 spores/ml, 10^4 spores/ml, 10^5 spores/ml, 10^6 spores/ml and 10^7 spores/ml was prepared. For each of these dilutions, 4.5 ml dH_2O was used to flood a 70 mm Whatman No.1 filter paper, which was left to air dry for 2 hours.

DNA isolation from spores

Individual spore traps designed for the preparation of DNA standards were divided into quarters, with each quarter to be used for one of four DNA isolation protocols: (i) the Schweigkofler *et al.* (2004) method; (ii) the Walsh *et al.* (1991) method; (iii) the Aljanabi and Martinez (1997) method and (iv) a modified version of the O'Donnell and Cigelnik (1997) method. The Schweigkofler *et al.* (2004) method involves washing the spores from the quarter filter paper spore trap and harvesting by spinning at a low centrifugal force (1000 rcf). The harvested spores were then disrupted by homogenisation with glass beads after which DNA was isolated using the standard CTAB treatments and phenol-chloroform-isoamyl alcohol, which are briefly as follows. Filter paper spore traps were washed with 20 ml 4xTE buffer (65 ºC) to remove the spores. The spores were resuspended in the 4xTE buffer by vortexing at a high speed for 5 min followed by centrifugation (1000 rcf; 90 min) after the removal of the filter paper. The supernatant (top layer) was removed and DNA extracted from the pellet (100 µl that remained in the tube) by homogenising with a glass bead for 30 s. A sample was subjected to three freeze-thaw cycles (2 min on ice, 2 min at 75 ºC, extending the last thaw to 30 min) after the addition of 300 µl CTAB extraction buffer. Phenol-chloroform-isoamyl alcohol (350 µl) was added to the tube and 250 µl of the supernatant was removed and placed into a new tube. The sample was finally purified using a GeneClean kit (Bio 101, Inc. Carlsbad, California). A volume of 3 µl of the supernatant was used directly for PCR.

The Walsh *et al.* (1991) method involved using a cation chelating agent, Chelex 100 Resin (Biorad, Hercules, USA). Briefly, this method entails the addition of the quarter filter paper spore trap to a total volume of 50 ml consisting of 5 g of the Chelex 100 Resin and sterilised distilled water. The sample with the Chelex slurry was then vortexed for 15 s at medium speed (speed 5) followed by centrifugation at a high speed (12 100 rcf) using a microcentrifuge for 30 s. The sample was incubated for 20 min at 95 ºC, and vortex for 15 s. Finally, the sample was centrifuged (12 100 rcf) for 60 s. Of the final supernatant, 3 µl was used directly in PCR.

The Aljanabi and Martinez (1997) method for isolating DNA from the spores found on a quarter filter paper spore trap entails the homogenisation of the filter paper spore trap for 15 s in 400 µl of a salt buffer. This method entails incubation of the samples at 65 ºC for 1 h after the addition of 40 µl 20 % sodium dodecyl sulfate (SDS) and 8 µl protenase K (20 mg/ml). To each sample 300 µl NaCl (6 M) was added and vortexed for 30 s at maximum speed. The final volume supernatant of 100 µl was transferred to a new tube after the centrifugation of the sample for 30 min at 10 000 rcf. Hundred µl of isopropanol was added to the supernatant, mixed and incubated for 1 h at -20 ºC. The precipitated nucleic acids were harvested by centrifugation for 20 min at 4 ºC and 10 000 rcf. The pellet was washed with 70 % ethanol, dried and resuspended in 40 µl dH_2O. A volume of 3 µl of the supernatant was used directly for PCR.

The fourth method was a modification of the standard CTAB and phenol-chloroform isolation method as previously described by O'Donnell and Cigelnik (1997). This method entailed the addition of a quarter filter paper spore trap and glass beads to a 2 ml screw-cap tube. Also added to the tube was 15 µl proteinase K (10 µg/µl) and 750 µl TES buffer. Following homogenisation in a homogeniser for 10 s, the tube was incubated for 1 h at 60 ºC with occasional vortexing. After the addition of 270 µl NaCl (5 M) and 120 µl CTAB (10 % volume), the tube was again vortexed and incubated for 10 min at 65 ºC. Following centrifugation (30 min; 4 ºC; 19 357 rcf), the supernatant (400 µl) was removed and placed in a new tube. After the addition of 400 µl phenol-chloroform, the tube was vortexed and centrifuged for 30 min at 4 ºC and 19 357 rcf. After repeating the phenol-chloroform extraction on 300 µl of the supernatant, a chloroform extraction was performed on 200 µl of the resulting supernatant to remove residual phenol. From the latter tube, 100 µl of the supernatant was transferred into a new tube and 60 µl isopropanol added to the supernatant, after which the sample was incubated overnight at -20 ºC. The precipitated nucleic acids were then harvested by centrifugation (30 min; 4 ºC; 19 357 rcf), washed with 70 % ethanol, air-dried and suspended in 40 µl dH_2O. A volume of 3 µl of the supernatant was used directly for PCR.

Real-time PCR

The first step to prepare a successful real-time PCR reaction is to determine the appropriate concentration and/or volumes of the fluorescent dye, DNA and primers as well as the annealing temperature. The volumes of fluorescent dye ranged from 6-10 µl and DNA from 1-3 µl. The primer mix concentrations ranged from 0.2-1 µM and the annealing temperature from 60-65 ºC. The optimum real-time PCR reaction consisted of 3 µl DNA (higher volumes of DNA resulted in inconsistent amplification and lower volumes resulted in no amplification of lower spore concentrations), 0.2 µM primer mix (higher concentrations of primers mix allowed the generation of primer-dimers) and 10 µl fluorescent dye made up to a total volume of 20 µl with distilled water. The annealing temperature ranged from 60 to 65 °C. All of the temperatures allowed the amplification of *F. circinatum*, however, only at 65 °C were the PCR reaction specific only for *F. circinatum*.

The four DNA isolation protocols were compared by conducting three real-time PCR runs on each standard. All the filter paper spore traps underwent four real-time PCR runs (using each quarter as a replicate) and the average of the four runs was calculated for a final spore concentration. Each real-time PCR reaction (20 µl) contained 10 µl SsoFast^{TM}EvaGreen® Supermix (BioRad, Hercules, California, USA), 0.75 µl CIRC1A (5’ CTTGGCTCGAGAAGGG 3’) and CIRC4A (5’ACCTACCCTACACCTCTCACT 3’) (Schweigkofler *et al.,* 2004) primer mix [Primer mix: 8 µl of 10 mM CIRC1A (Inqaba Biotech, South Africa), 8 µl of 10 mM CIRC4A (Inqaba Biotech, South Africa) and 4 µl dH_2O], 3 µl DNA and 6.25 µl dH_2O.

All real-time PCR runs were performed on a BioRad CFX 96 real-time machine (Hercules, California, USA) with the reaction conditions as follows: 95 °C for 10 min, 44 cycles (95 °C for 10 s, 65 °C for 15 s, and 72 °C for 30 s). Amplification was followed by a melting curve analysis for which the reaction conditions were as follows: 95 °C for 1 min, 40 °C for 1 min and 65 °C to 95 °C with a 0.1 °C increment. A computer with a Windows XP/Vista operating system enabled analysis of the C_t and melting curve using the CFX Manager software (Hercules, California, USA). C_t was determined according to the relative fluorescence for each well at each cycle (McCartney *et al.,* 2003). The melting temperature was determined by making use of the decrease in fluorescence with the increase in temperature.

RESULTS

DNA isolation from spores

All the DNA isolation protocols proved to be highly efficient in isolating DNA from the filter papers inoculated with *F. circinatum* spores. They all allowed detection of spore concentrations among the standards to as low as 10^3 spores/ml. The only exception was the Schweigkofler *et al.* (2004) protocol for which spores were only detected at 10^7 spores/ml (Table 1). Both the modified CTAB method and the Aljanabi and Martinez (1997) protocol allowed detection of spore concentrations from 10^2 through to 10^7 spores/ml, but took longer to conduct than the Walsh *et al.* (1991) protocol (Table 1). Thus the protocol chosen for DNA isolation of the naturally infected spore traps was the Walsh *et al.* (1991) method due to the protocol's sensitivity and the shorter time needed for DNA isolation.

Real-time PCR

Melting curve analysis was conducted to ensure that positive results were due to target DNA amplification and not due to primer-dimers. Target DNA and primer-dimers were distinguished using melt peaks that plot the regression of fluorescence (reduction in fluorescence) versus temperature. A positive peak is higher/above the threshold bar; a peak at a higher temperature indicating the target DNA and a peak at a lower temperature indicating a primer-dimer due to the primer's lower melting temperature. A positive peak at a higher temperature was thus considered a positive result.

Monitoring *F. circinatum* in a pine seedling nursery

Over the entire 52-week monitoring period, no spores were detected on any of the six spore traps during nine of the fortnightly sample collections, or the spore concentrations were too low to be detected. During eleven of the two-weekly sampling occasions, the average spore concentration was equal to or less than 10^3 spores/ml, while two of the samples had an average of 10^4 spores/ml and another two contained an average of 10^5 spores/ml. All the spore trap heights (positions) gave similar results, producing spore traps with concentrations from below 10^3 to 10^5 spores/ml, except for positions 3 and 4 that had a narrower spore concentration range (Table 2). The minimum temperatures had low variation over the 12-month period and the maximum temperatures showed greater variation (Table 2). The minimum temperatures ranged from 5 °C to 23 °C while the maximum temperatures ranged from 20 °C to 43 °C.

DISCUSSION

The real-time PCR used in this study was based on a non-specific dye, as it is more cost effective than those based on hydrolysis probes. Although previous authors (Schweigkofler *et al.,* 2004; Garbelotto *et al.,* 2008; Ioos *et al.,* 2009) were divided in their choice of detection system, both hydrolysis probes (Ioos *et al.,* 2009) and SYBR Green approaches (Schweigkofler *et al.,* 2004; Garbelotto *et al.,* 2008) are available for *F. circinatum*. Therefore, even though a hydrolysis probe system is generally believed to be more sensitive than a non-specific dye system, the latter can be used to reliably quantify the spores of the pitch canker fungus.

This study compared four DNA isolation protocols that differed not only in time required to complete the extractions but also in sensitivity. The Schweigkofler *et al.* (2004) protocol has been used in the past in a study that focussed on the detection and quantification of *F. circinatum* spores and the concentrations detected ranged from 10^3-10^6 spores/ml. In this study only very high spore concentrations (10^7 spores/ml) were detected with this method. This lack in sensitivity may be due to the extraction protocol being inferior (less effective) to other extraction protocols. The method also requires a variety of equipment and chemicals/reagents increasing the cost of this isolation method compared to other methods that require less equipment and chemicals/reagents. The Aljanabi and Martinez (1997) protocol and the newly developed, modified O'Donnell and Cigelnik (1997) method were the most sensitive and allowed detection of spore concentrations as low as 10^2/ml. However, Walsh *et al.* (1991) was the chosen method for extracting DNA from the spores found on the spore traps. Even though it is less sensitive than the Aljanabi and Martinez (1997) and the newly developed method, the Walsh *et al.* (1991) method was less time consuming and required fewer chemicals/reagents and less specialised equipment. The DNA isolation method (Walsh *et al.,* 1991) used during this study was cost-effective, sensitive and quick, a combination of characteristics not found in the other three isolation methods. It ultimately allowed detection of spore concentrations between 10^3-10^7 spores/ml.

The results of the current study agree with those reported by Schweigkofler *et al.* (2004). From the literature it also appears that the Ioos *et al.* (2009) real-time PCR assay is more sensitive than the Schweigkofler *et al.* (2004) assay. This is because it allows detection of only 8 fg DNA compared to the lower limit of 10 pg DNA or 10^3 spores/ml that were detected with the CIRC1A and CIRC4A primer pair. However, the Ioos *et al.* (2009) method differed not only in the fact that it included *F. circinatum* culturing/enrichment and a different DNA isolation method, but the authors also had different aims. The Schweigkofler *et al.* (2004) study focussed on detecting *F. circinatum* and developing an assay to trap and quantify the spore concentrations of the pathogen found on pine trees by using real-time PCR. The Ioos *et al.* (2009) study focussed on comparing enrichment procedures and DNA extraction kits to enable the detection of *F. circinatum* on pine seeds using real-time PCR.

The annealing temperature during PCR is important as it determines the sensitivity of the real-time PCR assay. The Schweigkofler *et al.* (2004) study included *Fusarium* species belonging to the *Gibberella fujikuroi* species complex to determine the specificity of the CIRC1A and CIRC4A primer pair and it was found that the primers were specific for only *F. circinatum* at an annealing temperature of 66 °C and higher.

The temperature range in the greenhouse can be expected to be narrower than the temperature range under normal environmental conditions as the greenhouse is a closed controlled system. At the highest minimum temperature of 23 °C (week 6) the average spore concentration was 10^4 spores/ml and at the lowest minimum temperature of 5 °C (week 30) the average spore concentration was lower (10^3 spores/ml), similar to the study of Garbelotto *et al.* (2008) that found that sporulation is limited at low temperatures. Between week 6 and week 20, there appeared to be a variation in average spore concentration, while between week 24 and week 50 the average spore concentration was constant. A possible explanation for this may be that the minimum and maximum temperatures between week 6 and week 20 were more stable (little variation) compared to the minimum and maximum temperatures between week 24 and week 50. The change in seedling numbers in the greenhouse over the 12-month period was not recorded, but could have had an effect on the variation in spore concentration over the study period.

The Garbelotto *et al.* (2008) study found that sporulation is higher under cool (not cold) wet conditions and warm conditions in the absence of rainfall. The pine seedling nursery that was the focus of this study is regularly irrigated, which may be the reason for an average spore concentration that did not exceed 10^4 spores/ml. Also the average temperatures ranged from mild to warm, temperatures that may be too high for enhancing sporulation.

The position of the spore traps appears to have had an effect on the spore concentrations detected. Spore concentrations were not the same between position 1 and 4 (2 m above ground) and between position 3 and 6 (0.2 m above ground). Spore concentration did, however, agree between positions 2 and 5 by having the same spore concentration range being detected ($\leq 10^3$ to 10^5). Position 2 and 5 were at the seedlings tray level and positions 1, 3, 4 and 6 were at levels where there is the possibility of more air movement, as there are no seedling trays to obstruct airflow. This may indicate that spores produced on the pine seedlings by *F. circinatum* are able to disperse by air but do not rise or fall much in level above ground during air transport.

The DNA isolation method used during this study proved to be sensitive, cost-effective and required limited chemical and equipment usage. Furthermore, the spore concentrations of *F. circinatum* could be successfully detected and quantified using real-time PCR. A non-specific dye was used due to its cost-effectiveness compared to a hydrolysis probe system and the success obtained during previous studies that used a similar dye. Thus the methods applied during this study can be refined to be used as a diagnostic technique in a commercial pine seedling nursery. In a commercial seedling nursery other data (humidity, wind speed, wind direction, spore trap height and human movement) should be included to ultimately determine the seasonal trends of *F. circinatum* for successful management strategies.

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TABLES

TABLE 1: Comparison between the DNA isolation protocols

Protocol	**Spore concentration (spores/ml)**†						**Time require to process samples (hours)**
	10^2	**10^3**	**10^4**	**10^5**	**10^6**	**10^7**	
Schweigkofler *et al*. (2004)	(-)	(-)	(-)	(-)	(-)	(+)	5 ‡
Walsh *et al*. (1991)	(-)	(+)	(+)	(+)	(+)	(+)	< 1
Aljanabi and Martinez (1997)	(+)	(+)	(+)	(+)	(+)	(+)	3.5
Newly developed protocol	(+)	(+)	(+)	(+)	(+)	(+)	> 24

(-) The *F. circinatum* target fragment was not detected

(+) The *F. circinatum* target fragment was detected

† No detection of the *F. circinatum* target fragment at spore concentrations of 10^0 and 10^1

‡ Only a limited number of samples can be processed simultaneously as a centrifuge can only spin 6 falcon tubes at a time

TABLE 2: Summary of spore concentrations detected in the FABI Greenhouse during the study

Week	Start date	Spore trap structures and position† Structure 1: 1 2 m above ground	2 0.8 m above ground	3 0.2 m above ground	Structure 2: 4 2 m above ground	5 0.8 m above ground	6 0.2 m above ground	Temperature (ºC) Average	Min.	Max.
2	10 Nov	*	*	*	*	*	*		18	26
4	24 Nov	*	*	*	*	*	*		18	31
6	8 Dec	*	10^4	*	*	*	*	10^4	23	30
8	22 Dec	*	*	*	*	*	*		18	32
10	5 Jan	$\leq 10^3$	10^4	*	*	*	*	10^3	22	31
12	19 Jan	10^4	10^4	*	10^4	*	10^3	10^4	21	42
14	2 Feb	10^5	10^5	*	*	*	10^5	10^5	17	29
16	16 Feb	*	$\leq 10^3$	$\leq 10^3$	*	*	$\leq 10^3$	$\leq 10^3$	17	30
18	2 Mar	*	*	*	10^2	10^3	10^2	10^2	17	33
20	16 Mar	10^5	*	*	*	*	*	10^5	17	28
22	30 Mar	*	*	*	*	*	*		18	41
24	13 Apr	$\leq 10^3$	*	$\leq 10^3$	10^3	10^3	10^3	10^3	#	#
26	27 Apr	10^3	$\leq 10^3$	$\leq 10^3$	10^3	10^3	*	10^3	#	#
28	11 May	$\leq 10^3$	10^4	10^3	10^3	10^4	*	10^3	15	31
30	25 May	$\leq 10^3$	*	*	10^3	*	*	10^3	5	43‡
32	8 Jun	$\leq 10^3$	10^3	$\leq 10^3$	10^3	$\leq 10^3$	*	$\leq 10^3$	15	30

Week	Start date	Spore trap structures and position†						Temperature (°C)		
		Structure 1			Structure 2					
		1 2 m above ground	2 0.8 m above ground	3 0.2 m above ground	4 2 m above ground	5 0.8 m above ground	6 0.2 m above ground	Average	Min.	Max.
34	22 Jun	*	$\leq 10^3$	10^3	*	10^5	*	10^3	18	26
36	6 Jul	*	*	$\leq 10^3$	*	*	*	$\leq 10^3$	18	20
38	20 Jul	*	*	*	*	*	*		8	21
40	3 Aug	*	*	*	*	*	*		10	25
42	17 Aug	*	*	$\leq 10^3$	*	$\leq 10^3$	*	$\leq 10^3$	10	29
44	31 Aug	*	*	*	*	*	*		11	31
46	14 Sept	*	*	*	*	*	*		16	34
48/50	12 Oct	*	$\leq 10^3$	*	*	$\leq 10^3$	$\leq 10^3$	$\leq 10^3$	17	35
52	26 Oct	*	*	*	*	*	*		17	27

† All entries represent the average of four real-time PCR experiment results

* Indicates samples in which *F. circinatum* was not detected due to fungus absence or presence at a level below the real-time PCR detection limit

No data available

‡ At week 30 the highest maximum of 43 °C occurred, an uncharacteristic temperature during the winter season. This may be due to either a broken thermometer or the greenhouse fans that did not switch on when the inside temperature of the greenhouse reached 25 °C.

Weeks 48/50 were combined

SUMMARY

This project focussed on the pine pathogen *Fusarium circinatum* as this fungus is responsible for great economic losses and endangering pine forests worldwide. A better understanding of this pathogen could lead to improved disease management, thus limiting the dispersal of the fungus. A diagnostic technique, whether non-DNA-based or DNA-based, should be chosen with care to ensure obtaining accurate results, limiting expenses and time needed to complete a project. This study reviewed the techniques used for the identification and detection of *Fusarium* species. Non-DNA-based and DNA-based techniques focus on the morphological or chemical traits, and nucleotide sequence respectively. This review enabled the selection of an appropriate detection and quantification technique for *F. circinatum*, as the advantages and disadvantages of all techniques were considered and compared.

The intergenic spacer (IGS) region of the ribosomal RNA repeat module is a popular diagnostic marker for *Fusarium* species due to the region's multiple copies in the genome and fast evolution rate. This marker was evaluated to determine if it could be used for *F. circinatum* diagnostics. The results confirmed the IGS region to be a good diagnostic marker, due to the region's species specificity, by comparing the IGS region of *F. circinatum* and other *G. fujikuroi* complex species. The results of phylogenetic analysis of all the isolates included in this study were supported by those of previous studies that also focussed on the IGS region.

Real-time PCR was used successfully for the detection and quantification of *F. circinatum* during past studies. Due to these successes, real-time PCR was chosen as the technique for the quantification of *F. circinatum* spores in a pine seedling nursery. The results of this study showed that the real-time PCR technique employed was specific and sensitive as it allowed detection of low spore concentrations. The study also showed that there is a correlation between spore production and temperature and that spore dispersal is possibly, but not exclusively, due to air movement. Real-time PCR can thus be used for future studies that focus on the detection and quantification of *F. circinatum* as this study has shown this technique to be effective.

APPENDIX 1

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                                          10        20        30        40        50        60        70        80        90        100       110
                                 ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331          ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum CAL2511            ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum FL2483             ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum FL2497             ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum MEX4900            ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTTTTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum FL2496             ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum SA0041             ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum MEX2248            ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum SA0010             ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum FL2472             ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum SA1834             ACTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum MEX2265            ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. circinatum SP5498             ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. subglutinans NRRL22016        ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. begoniae NRRL25300            ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL25346           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL25204           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL26756           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL26757           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL25623           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL25195           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. succisae NRRL13613            ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. anthophilum NRRL13602         ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL29123           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. bulbicola NRRL13618           ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp. NRRL25807           ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
Fusarium sp.  NRRL25622          ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. bacterioides NRRL20476        ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. pseudoanthophilum NRRL2520    ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. verticillioides NRRL22172     ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. thapsinum NRRL22045           ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. concentricum NRRL25303        ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. fractiflexum NRRL28852        ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. fujikuroi NRRL13566           ATTCTTCCACGGCGCTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. globosum NRRL26131            ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. proliferatum NRRL22944        ATTCTTCCACGGCACTCGAAGCGTGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. oxysporum NRRL22902           ATTCTTCCACGGCGCTCGAAGCGCGTCGTGGTATTTCGCGTATTGTAATTTCAACACGAGCGGGGTCAAATCCTTTGCAGACGACTTAGCTGTGCGAAACGGTCCTGTAA
F. subglutinans MRC8553          --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554          --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512          --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802          --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864        --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301         --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867        --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549         --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105              --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617              --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794              --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602              --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929              --------------------------------------------------------------------------------------------------------------
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	120 130 140 150 160 170 180 190 200 210 220
	....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum CAL2511	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum FL2483	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum FL2497	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum MEX4900	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum FL2496	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGAAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum SA0041	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum MEX2248	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum SA0010	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum FL2472	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGAAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum SA1834	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum MEX2265	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. circinatum SP5498	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. subglutinans NRRL22016	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-TT
F. begoniae NRRL25300	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCTGGATTTCTGGAGACTTGTAGGGG-TTGTGGGTTT
Fusarium sp. NRRL25346	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGGTTT
Fusarium sp. NRRL25204	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-AT
Fusarium sp. NRRL26756	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-TT
Fusarium sp. NRRL26757	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-TT
Fusarium sp. NRRL25623	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTCCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-TT
Fusarium sp. NRRL25195	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-TT
F. succisae NRRL13613	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCCGGAGACTTGTAGGGG-TTGTGGG-TT
F. anthophilum NRRL13602	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-TT
Fusarium sp. NRRL29123	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. bulbicola NRRL13618	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
Fusarium sp. NRRL25807	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
Fusarium sp. NRRL25622	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGA-CT
F. bacterioides NRRL20476	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. pseudoanthophilum NRRL2520	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGGTTTGTGGG-CT
F. verticillioides NRRL22172	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. thapsinum NRRL22045	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGGCTTGTAGGGG-TTGTGGG-CT
F. concentricum NRRL25303	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-AC
F. fractiflexum NRRL28852	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-CT
F. fujikuroi NRRL13566	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-AT
F. globosum NRRL26131	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCTGGATTTCCGGAGACTTGTAGGGG-TTGTGGG-AT
F. proliferatum NRRL22944	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCTGGATTTCCGGAGACTTGTAGGGG-TTGTGGG-AT
F. oxysporum NRRL22902	GCAGTAGAGTAGCCTTGTTGTTACGATCTGCTGAGGGTAAGCCGTCCTTCGCCTCGATTTCCCCAATGGGTTCTCCGGATTTCTGGAGACTTGTAGGGG-TTGTGGG-AT
F. subglutinans MRC8553	--
F. subglutinans MRC8554	--
F. subglutinans MRC6512	--
F. subglutinans MRC2802	--
F. proliferatum CMW 12864	--
F. proliferatum MRC 2301	--
F. proliferatum CMW 12867	--
F. proliferatum MRC 8550	--
F. proliferatum MRC 8549	--
F. oxysporum CAV105	--
F. oxysporum CAV617	--
F. oxysporum CAV794	--
F. oxysporum CAV602	--
F. oxysporum CAV929	--

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                                   230       240       250       260       270       280       290       300       310       320       330
                              ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331       TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum CAL2511         TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum FL2483          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum FL2497          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum MEX4900         TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGARWTTYMT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum FL2496          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum SA0041          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum MEX2248         TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum SA0010          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGKKGRATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum FL2472          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum SA1834          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum MEX2265         TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. circinatum SP5498          TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTG-------
F. subglutinans NRRL22016     TTTTTCGATTGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGCACTCTGTG-------
F. begoniae NRRL25300         TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGGACTTTGTG-------
Fusarium sp. NRRL25346       TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGAACTTTGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGGACTTTGTG-------
Fusarium sp. NRRL25204       TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGGGCTTTGTG-------
Fusarium sp. NRRL26756       TTTTTCGA-TGCGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGGCTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGGACTTTGTG-------
Fusarium sp. NRRL26757       TTTTTCGA-TGCGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGGCTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGGACTTTGTG-------
Fusarium sp. NRRL25623       TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGGACTTTGTG-------
Fusarium sp. NRRL25195       TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGGGCTGGACTTGGTGGAATTTGAT----------TCCGTCGAGTCTGGCAGGACTTTGTG-------
F. succisae NRRL13613         TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCGGGACTTTGTGCGGCTGT
F. anthophilum NRRL13602      TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTACAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGCCTGGCAGGACTTTGTG-------
Fusarium sp. NRRL29123       TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTTCAT----------TCCGTCGAGTCTGGCAGCACTTTGTG-------
F. bulbicola NRRL13618        TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTCGAT----------TCCGTCGAGTCTGGCAGGACTGTGTG-------
Fusarium sp. NRRL25807       TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTCGAT----------TCCGTCGAGTCTGGCAGGATTGTGTA-------
Fusarium sp.  NRRL25622      TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTCGAT----------TCCGCTGAGTCTGGCAGGACTGTGTG-------
F. bacterioides NRRL20476     TTTTTCGA-TGTGTCGTCTCTGGACGGGCGGTTCAGGGTAGTCGAGTTGGACTTGGTGGAATTCGAT----------TCCGTTGAGTCTGGCAGGACTGTGTG-------
F. pseudoanthophilum NRRL2520 TTTTTCGA-GATGTCGTCTCCGGACGGGCGGTGCAGGGTAGTCGGGTTGGACTTGGTGGAATTCGCT----------TTCCTCGAGTCTGGCACGATTGTGTG-------
F. verticillioides NRRL22172  TTTTTCGA-GATGTCGTCTCCGGACGGGCGGTGCAGGGTAGCCGAGTTGGACTTGGTGGAATTCGAT----------TCCTTCGAGTCTGGCACGATTGTGTG-------
F. thapsinum NRRL22045        TTTTTCGA-GATGTCTTCTCCGGACGGGCGGTGCAGGGTAGTCGAGTCGGACTTGGTGGAATTCGAT----------TCCTCCGAGTCTGGCACGATTGTGTG-------
F. concentricum NRRL25303     TTTT--GA-TGTGTCGTCTCCGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTTGTGGAATTCGAT----------TCCGTCGAGTCTGGCATGGCTGTGTG-------
F. fractiflexum NRRL28852     TTTC--GA-TGTGTCGTCTCCGGACGGGCGGTGCAGGGTAGCCGAGTTGGACTTGGTGGAATTCGAT----------TCCGTCGAGTCTGGCATGGCTGTCTG-------
F. fujikuroi NRRL13566        CTTT--GA-TGTGTCGTCTCCGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTCGAT----------TCCGTCGAGTCTGGCGCGAGTGTGTG-------
F. globosum NRRL26131         TTTT--GA-TGTGTCGTCTCCGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTCGGTGGAATTCGAT----------TCCGTCGAGTCTGGCATGGCTGTGTG-------
F. proliferatum NRRL22944     TTTT--GA-TGTGTCGTCTCCGGACGGGCGGTGCAGGGTAGTCGAGTTGGACTTGGTGGAATTCGAT----------TCCGTCGAGTCTGGCATGGCTGTGTG-------
F. oxysporum NRRL22902        TTTT--GA-TGTGTCGTCTCCGGACGGGCGGTGCAGGGTAGTCGAGCTAGACTTGGTGGAATTCCGTCGATAGGAGTTCCGTCGAGTCTGGT------------------
F. subglutinans MRC8553       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802       --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864     --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301      --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867     --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550      --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549      --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929           --------------------------------------------------------------------------------------------------------------
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                                           340       350       360       370       380       390       400       410       420       430       440
                                  ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331           --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum CAL2511             --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum FL2483              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum FL2497              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTKCTTGGKCTTGGTCGATTTGAGGATCGATTCGAGGGSTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum MEX4900             --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum FL2496              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum SA0041              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum MEX2248             --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum SA0010              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum FL2472              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum SA1834              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTATGCGGT
F. circinatum MEX2265             --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTTCATTCCGTCGAGTCTGGCGGGAC--T-TTG-------TGCGGCTGTGTGYTGKAYKGT
F. circinatum SP5498              --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGAT------------------------------------------------------------
F. subglutinans NRRL22016         --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTAGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAACTTGAGGTGTATTCGGT
F. begoniae NRRL25300             --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTAAGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAATGCAAGGTGTATGCGGT
Fusarium sp. NRRL25346            --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTAGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAACTTGAGGTGTATGCGGT
Fusarium sp. NRRL25204            --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTCGTCTTGGTCGATTCGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAGCTTGAGGTGTGTAGAGT
Fusarium sp. NRRL26756            --CGGCTGTGTGCTGGACGATGCAGGGTAGGCTGCTTAGTCTTGGTCGATTTAAGGATCGATTCGAGGGCTGGGC--G-CTG-------GCAACTTGAGGTGTGTAGAGT
Fusarium sp. NRRL26757            --CGGCTGTGTGCTGGACGATGCAGGGTAGGCTGCTTAGTCTTGGTCGATTTAAGGATCGATTCGAGGGCTGGGC--G-CTG-------GCAACTTGAGGTGTGTAGAGT
Fusarium sp. NRRL25623            --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTAGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GGAACTTGAGGTGTATGCGGT
Fusarium sp. NRRL25195            --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTACTTAGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAACGTGAGGTGTATGCGGT
F. succisae NRRL13613             GTCGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGACTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAACTTGAGGTGTATGCGGT
F. anthophilum NRRL13602          --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTGTTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTAACTTGAGGTGTATGCGGT
Fusarium sp. NRRL29123            --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTAGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GTGACTTGAGGTGTATGCGGT
F. bulbicola NRRL13618            --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTCGAGGATCGATTCCAGGGCTGGGC--G-TTG-------GTAACTTGAGGTGTGTGCGGT
Fusarium sp. NRRL25807            --CGGCTGTGTGGTGGACGGTGCAGGGTAGGCTGCTTGGTCTTGGTCGATTCGAGGATCGATTCCAGGGCTGGGC--G-TTG-------GTAACTTGAGGTGTATGCGGT
Fusarium sp.  NRRL25622           --CGGCTGTGTGTTGGACGGTGCAGGGTAGGCTGCTCAGTCTTGGTCGATTTGAGGATCGATTCGAGGGCTGGGC--G-CTG-------GCAACTTGAGGTGTATGCGGT
F. bacterioides NRRL20476         --CGGCTGTGTGTTGGACGGTGCAGGGTAGGCTGGTCAGTCTTGGTCGATTTGGGGAGTGATTCGAGGGCTGGGC--G-CTG-------GTAACTTGTGGTGTATGCGGT
F. pseudoanthophilum NRRL2520     --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTCTGTCTTGGTCGATTCAAAGATCGATTCGAGGGCTGAGG--G-CCGGCCGTGAGTTGTGTGTGAGGGATGCGGT
F. verticillioides NRRL22172      --CGGCTGTGTGTTGGACGGTGCAGGGTAGGCTACTCAGTCTTGGTCGATTCGAGGATCGATTCGGGGGCTGAGT--G-TCG-------ACTGTGTGTGAGGGATGGGGT
F. thapsinum NRRL22045            --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCTGCTC-------------------------------------------------------------------------
F. concentricum NRRL25303         --CGGCTGTGTGTTGGACGGTGCAGGGTAGGCGGCTCGGTCTTGGTCGATTCGAGGGCTG-------------------GCG-------GTTGAGTGAGGTGGGTGCGGT
F. fractiflexum NRRL28852         --CGGCTGTGTGCTGGACGGTGCAGGGTAGGCGGCTCGGTCTTGGTCGATTCGAGGATCGATTCGAGGGCTGGCC--G-TCG-------AGTAAGTGAGATGGGTGCGGT
F. fujikuroi NRRL13566            --CGGCTGTGTGTTGGACGGTGCAGGGTAGGCGGCTCGGTGTTGGTCGATTCGAGGATCGATTCGAGGGCTGGCT--G-TCG-------AGTAAGTGAGATGGGTGCGGT
F. globosum NRRL26131             --CGGCTGTGTGTTGGACGGTGCAGGGTAGGCGGCTCGGTCTTGGTCGATTTGATGATCGATTCGAGGACCGGCC--A-CAG-------AGGATGTGGGATAGATGGGGT
F. proliferatum NRRL22944         --CGGCTGTGTGTTGGACGGTGCAGGGTAGGCGGCTCGGTCTTGGTCGATCTGATGATCGATTCGAGGGCCGGCC--ACCAG-------AGGATGTGGGATGGAGGGGGT
F. oxysporum NRRL22902            --CGGCTGTGTGTTGGACGGTGTAGGGTAGGCTGCTTGGACATGGTCGGTTCGAGGATCGATTCGAGGGGCCGGCCTG-TCG-------ATGATGTGTGATGTATGCGGT
F. subglutinans MRC8553           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802           --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301          --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550          --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549          --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929               --------------------------------------------------------------------------------------------------------------
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                                      450       460       470       480       490       500       510       520       530       540       550
                              ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331       CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum CAL2511         CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum FL2483          CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum FL2497          CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCRGCTTAGACTTGGTCGATC
F. circinatum MEX4900         CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum FL2496          CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum SA0041          CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum MEX2248         CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum SA0010          CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum FL2472          CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum SA1834          CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum MEX2265         GCAGGGTAGGCTGCTTGGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. circinatum SP5498          -----------------------------------------------------------------------------GGTGCAGGGTAGGCGGCTTAGACTTGGTCGATC
F. subglutinans NRRL22016     CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCCGATCGAGGTTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. begoniae NRRL25300         CTAGGGTAGGCTGGTTTGTC-TTGGTCAAATCTGATGTCGGCTTCCGTGCGGACCAGATCGAGCTTGGTACAGGTTAGGTACAGGGTAGGCGGCGTAGACTTGGTCGATC
Fusarium sp. NRRL25346        CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCTTGGTATAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
Fusarium sp. NRRL25204        CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGAGGTTGGCTTCCGTGCGGACCAGATCGAGCATGGTATAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
Fusarium sp. NRRL26756        CTAGGGTAGGCTGGTTTGTC-TTGGTCGAGTTTGATGTTGGCTCCCGTGCGGACCAGATCGAGCATGGTGCAGGGTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
Fusarium sp. NRRL26757        CTAGGGTAGGCTGGTTTGTC-TTGGTCGAGTTTGATGTTGGCTCCCGTGCGGACCAGATCGAGCATGGTGCAGGGTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
Fusarium sp. NRRL25623        CTAGGGTAGGCTGGCTTATC-TTAGTCAAATTTGATGTTGGCTCCCGTGCGGACCAGATCGAGCGTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
Fusarium sp. NRRL25195        CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATCTGATGTCGGCTTCCGTGCGGACCAGATCGAGCTTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. succisae NRRL13613         CTAGGGTAGGCTGATTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGACCAGATCGAGCTTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGACC
F. anthophilum NRRL13602      CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTTCCGTGCGGCCCAGATCGAGCTTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTTGA--
Fusarium sp. NRRL29123        CTAGGGTAGGCTGGTTCGTC-TTTGTCAAATTTGATGTTGGCTTCCGTGCGGACCAGGTCGAGCTTGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. bulbicola NRRL13618        CTAGGGTAAGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTCCCGTGCGGACCAGATCGGGCATGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGCCGATC
Fusarium sp. NRRL25807        CTAGGGTAAGCTGGTTTGTC-TTGGTCGAATTTGATGTTGGCTCCCGTGCGGACCAGATCGAGCATGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGCCGATC
Fusarium sp.  NRRL25622       CTAGGGTAGGCTAGTTTGTC-TTGGTCGAATTTGATATTGGCTCCCGTGCGGACTAGATCGGGCATGGTACAGGTTAGGTACAGGGTAGGCGGCTTAGACTTGGTCGATC
F. bacterioides NRRL20476     CTAGGGTGGGCTGGTTTGTCTTTTGTCGAATTTGATGTTGGCTCCCGTGCGGACTAGATCGAGCGTGGTCCAGGTTAGGTACAGGGTAGGCGGCCTAGACTTGGTCGATC
F. pseudoanthophilum NRRL2520 CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATCTGATGTCGGCTCCCGTGTAGAGCGCAGCGAGGGTGGTGCAGGGTAGGTACAGGGTAGGCAGCTTAGACTTGGTCGATC
F. verticillioides NRRL22172  CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATCTGATGTCGGCTGCCGTGTAGGACGGAACGATGGTGGTGCAGGGTAGCTATAGGGTAGGCAGCTTAGACTTGGTCGATC
F. thapsinum NRRL22045        ------------------------------------------------------------------------------------------------AGACTTGGTCGATC
F. concentricum NRRL25303     CTAGGGTAGGCTGGTTTGTC-TTGGTCGAGTTCGATGTCGGCTCTCGTGTAGAACAGAGCGAGCGTGGTTCAGGGTAGGTACAGGGTAGGCAGCTTAGACCTGGCCGATC
F. fractiflexum NRRL28852     CTAGGGTAGGCTGGTTTGTC-TTGGTCGAGTTCGATGTCGGCTCCCGTGTAGAACAGAGCGAACGTGGTCCAGGGTAGGTACAGGGTAGGCAGCTTAGACTTGGTCGATC
F. fujikuroi NRRL13566        CTAGGGTAGGCTGGTTTGTC-TTGGTCGAATTCGATGTCGGCTCCTGTGTGGAACAGAGCGAGAGTGGTCCAGGGTAGGTACAGGGTAGGCAGCTTAGACCTGGTCGATC
F. globosum NRRL26131         CTAGGGTAGGCTGGTTTGTC-TTGGTCGAACTCGATGTCGGCTCCCGTGCAGACCAGAACGAGGGTGGTGCAGGGTAGGTACAGGGTAGGCAGCTTAGACTTGGTCGATC
F. proliferatum NRRL22944     CTAGGGTAGGCTGGTTTGTC-TTGGTCGAACTCGATGTCGGCTCCCGTGCAGACCAGAGCGAGCGTGGTCCAGGGTAGGT-----------AGCTCGGCCTTGGTCGATC
F. oxysporum NRRL22902        CTAGGGTAGGCTGGTTTGTC-TTGGTTCAATTTGATGTCGGCTCCCGTGCAGGCCAGAGTGAG-GGGGTCCAGGGTAGGTACAGGGTAGGCAGCTTAGGTTTGGTCGATC
F. subglutinans MRC8553       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802       --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864     --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301      --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867     --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550      --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549      --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929           --------------------------------------------------------------------------------------------------------------
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	560 570 580 590 600 610 620 630 640 650 660
	....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum CAL2511	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum FL2483	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum FL2497	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum MEX4900	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum FL2496	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum SA0041	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum MEX2248	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum SA0010	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum FL2472	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum SA1834	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum MEX2265	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. circinatum SP5498	TGGATGTCGG-TTCTCTGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. subglutinans NRRL22016	TGGATGTCGG-TTCTCTGGCTGACGGATCCCAGAGCTTCGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. begoniae NRRL25300	TGGATGTCGT-TTCTCCGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGCAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGGCAGGATGCGATTCGCGTTGAG--ATG
Fusarium sp. NRRL25346	TGGATGTCGG-TTCTCCGGCTGACGGATCTCAGAGCTTCGGAACGAGATGGGAGTAGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
Fusarium sp. NRRL25204	TGGATGTCGG-TTCTCCGGCTGACGGATCTCAGAGCTTCGGAAGGAGATGGGAGTAGTGCAGGGTAGGCAGCTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
Fusarium sp. NRRL26756	TGGATGTTGG-TTCTCTGGCTGACGGATCTCAGAGCTTCGGAACGAGATGGGAGTGGTGCAGGGTAGGCAGCTTCTGTCTCTGCCAGGATGCGATTCGCGTTGAG--ATG
Fusarium sp. NRRL26757	TGGATGTTGG-TTCTCTGGCTGACGGATCTCAGAGCTTCGGAACGAGATGGGAGTGGTGCAGGGTAGGCAGCTTCTGTCTCTGCCAGGATGCGATTCGCGTTGAG--ATG
Fusarium sp. NRRL25623	TGGATGTCGG-TTCTCCGGCTGACGGATCTCAGAGCTTTGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
Fusarium sp. NRRL25195	TGGATGTCGC-TTCTCCGGCTGACGGATCTCAGAGCTTCGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGTCAGGATGCGATTCGCGTTGAG--GTG
F. succisae NRRL13613	TGGATGTCGG-TTCTCTGGCTGACGGTTCTCAGAGCTTCGGAACGAGATGGGAGTGGTGCAGGGTAGGCAGCTTCTGTCTTTGCCAGGATGCGATTAGCGTTGAG--ATG
F. anthophilum NRRL13602	--------------TCTGGCTGACGGATCTCAGCGCTTCGGAACGAGATGGGAGTGGTTCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTCGAG--GTA
Fusarium sp. NRRL29123	TGGATGTCGG-TTCTCTGGCTGACGGATCCCAGAGCTTCAGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGCGTTGAG--ATG
F. bulbicola NRRL13618	TGGGTGTCGG-TTCTCTGGCTGGCGGACCTCAGAGCTTCGGAACGAGATGGGAGTAGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGTGTTGAG--GTG
Fusarium sp. NRRL25807	TGGGTGTCGG-TTCTCTGCCTGGCGGACCTCAGAGCTTCGGAACGAGATGGGAGTAGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTCGTGTTGAG--GTG
Fusarium sp. NRRL25622	TGGATGTCGG-TTCTCCGGCTGACGGATCTCAGGGCTTCGGAACGAGATGGGAGTGGTGCAGGGTAGGCAACTTCTGTCTTTGCCAGGATGCGATTTGTATTAGG--ATG
F. bacterioides NRRL20476	TGGATGTTGT-TTCTCTGGCTGGCGGATCTCAGGGCTTTGGAACGAGATGGGAGTGGTACAGGGTAGGCAACTCCTGTCTTTGCCAGGATGCGATTTGTGTTGAG--ATG
F. pseudoanthophilum NRRL2520	TGGATGTCGG-TTCTCTGGCTGACGGGTCTGAGGTCGTCGAAACGAGATGCGACTGGTGCAGGGTAAGCAGCTTCCGTATCGGCCGGGAAGTGATTCGAATTGAGATATG
F. verticillioides NRRL22172	TGGGTGTCGGTTTCCCTGGCTGGCGGGTCTGAGGTCGTCGAGACGAGATACGAGTGGTGCAGGGTAAGCAGCTTCTGTATCTGCCAGGAAGCGATTCG------------
F. thapsinum NRRL22045	TGGATGTCGG-TTCTCTGGCTGACGGGTCTGAGGTCGCTGAAACGATACGGGGCTGGTGCAGGGTAGGCAACTTCTGACT--GCCGGGAAGCGATTCGAATCGAG--TTG
F. concentricum NRRL25303	TGGATGTCGG-TTCTCTGGCTGATGGATCTGAGAGCGTCGAAACGAGATGCGGGCGCTGCAGGGTAGGTAACTTCTGTCT--GTCAGGAAGCGATTTGTGTTGAG--ATG
F. fractiflexum NRRL28852	TGGATGTCGG-TTCTCCGGCTGATGGATCTGAGACCGTCGAAACGAGATGCGGGCGCTGCAGGGTAGGTAACTTCTGTCCTCGTCAGGAAGCGATTCGTGTTGAG--ATG
F. fujikuroi NRRL13566	TAGATGTCGG-TTCTCTGGCTGATGGATCTGAGACCGTCGAAACGAGATGCGGGCGCTGCAGGGTAGGTAACTTCTATCTTCGGCAGGAAGCGATTCGTGCTCAA--ATG
F. globosum NRRL26131	TGGATGTTAG-TTCTCTGGCTGATGGATCTGAAAGCGTCAAAACGAGATGCGGGCGCTGCAGGGTAGGTAACTTCTGTCTTCGTCAGGAAGCGATTTGTGTTGAG--ATG
F. proliferatum NRRL22944	TGGATGTCGG-TTCTCTGGCTGATGGGTCTGGGACCGTCAAAACGAGATGCGGGCGCTGCAGGGTAGGTAACTTCTGTCTTCGTCAGGAAGCGATTCGTGTTGAG--ATG
F. oxysporum NRRL22902	TGGAGGTCGA-TTCTCCGGCTGGCGGATCTGACACTGTCGAAACGAGATGCGAGCGGTGTAGGGTAGGCTAGTTTCGTCCTCGCCAGGTTGCGATTTG-GACGAG--ATG
F. subglutinans MRC8553	--
F. subglutinans MRC8554	--
F. subglutinans MRC6512	--
F. subglutinans MRC2802	--
F. proliferatum CMW 12864	--
F. proliferatum MRC 2301	--
F. proliferatum CMW 12867	--
F. proliferatum MRC 8550	--
F. proliferatum MRC 8549	--
F. oxysporum CAV105	--
F. oxysporum CAV617	--
F. oxysporum CAV794	--
F. oxysporum CAV602	--
F. oxysporum CAV929	--

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                                          670       680       690       700       710       720       730       740       750       760       770
                                  ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331           TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum CAL2511             TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum FL2483              TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum FL2497              TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum MEX4900             TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum FL2496              TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum SA0041              TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum MEX2248             TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum SA0010              TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum FL2472              TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum SA1834              TGCGGTCCTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAGTTTCGTCGCT-ACAGTTTGCCA---------TAGGTGTAGGGTAGGGTACAGGGTAGGCAGATTTCT
F. circinatum MEX2265             TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. circinatum SP5498              TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. subglutinans NRRL22016         TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAA-TTTCGCTGCT-ACAG-CTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. begoniae NRRL25300             TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTCTGTCGCT-ACGG-TTTGCTA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
Fusarium sp. NRRL25346            TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAATTCTCAA-TATCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
Fusarium sp. NRRL25204            TGCGGT-CTAGGTTAGG-TACAGGGTAGGAAGAG-TCTCAA-TATCGTCGCT-ACAG-TTTGTCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
Fusarium sp. NRRL26756            TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAA-TTTCGTTGCT-ATAG-CTTACCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCC
Fusarium sp. NRRL26757            TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAA-TTTCGTTGCT-ATAG-CTTACCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCC
Fusarium sp. NRRL25623            TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAA-TTTCGTCGCT-ACAG-TTTGCCA---------TGGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
Fusarium sp. NRRL25195            TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAG-TTCCGTCGCT-ACCG-TTTGCTA---------TAGGTGTAGGGTA-GGTACAGGGTAGGTAAATTTCT
F. succisae NRRL13613             TGTGGT-CTAGGTTAGG-TACAGGGTAGGCAGAA-TCTCAA-TTTCGTCGCT-ACAG-TTTGCCA---------AAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. anthophilum NRRL13602          CGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TCTCAA-TTTCGTCGCT-ACAG-TTTGCCA---------TAGGTGTAGGGTA-GATACGGGGTAGGCAGATTTCT
Fusarium sp. NRRL29123            TGCGGT-CTAGGTTAGG-TACAGGGTAGGTAGGA-TCTCAA-TTTCGCTGCT-TTAG-CTTGCCA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
F. bulbicola NRRL13618            TGTGGT-CTAGGTCAGG-TACAGGGTAGGTAGAA-TTCCAA-TTTCGTCGCT-ACAT-TTTGCTA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
Fusarium sp. NRRL25807            TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TTCCAG-TTTCGTCGCT-ATAT-TTTGCTA---------TAGGTGTAGGGTA-GGTACAGGGTAGGCAGATTTCT
Fusarium sp.  NRRL25622           TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGAA-TTCCAG-TTTTGTTGCT-ACAT-TTGGCTA---------TAGGTGTAGGGCA-GGTACAGGGTAGGCAGACTTTT
F. bacterioides NRRL20476         TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAAAA-TTCCAG-TTTTGTTACT-ATAT-TTTGCTA---------TAGGTATAGGGTA-GGTACAGGGTAGGCAGATTTTT
F. pseudoanthophilum NRRL2520     TGTGGT-CTAGGTTAGG-TACAGGGTAGGTAGGT-CTTCAG-TTTTGTCGCTGATGG-ACTGCTG---------CGGGTGCAGGGTA-GGTACAGGGTAAGCAGATTTCT
F. verticillioides NRRL22172      ---GGT-CTAGGTTAGG-TACAGGGTAGGCGAGT-TTCCAG-TCTCGTCGCTGATGG-ATTGCTG---------CGGGTGTAGGGTA-GGTACAGGGTAAGCAGATCTCT
F. thapsinum NRRL22045            TGTGGT-CTAGGTTAGG-TACAGGGTAGGTGGAA-TTCCAG-CTTCGTCGCGGAAAG-ATCGCAG---------CAGGTGAAGGATA-GGTACAGAGTAGGCAAGTTTCT
F. concentricum NRRL25303         TGTGGT-CTATGT--GG-TACAGGGTAGGCAAGT-TC-----TTTACCAGAA-ATCG-ATTGGCAGTAAGATATATGGTCTAGGATA-GGTACAGGGTAGGTAAATATCT
F. fractiflexum NRRL28852         TGAGGT-CTAGGTTAGG-CACAGGGTAGGCAAGT-TCTTCC-TCTACCAGAA-ATCG-ATTGGCAATAAGATATATAGTCTAGGTTA-GGTACAGGGTAGGTAAATATCT
F. fujikuroi NRRL13566            TATGGT-CTAGGTTAGG-TACAGGGTAGGCAAGT-TCTTTC-TCTACCAGAA-ATCG-ATTGGCAATAGGATATATAGTCTAGGGCA-GGCACAGGGTAGGTAAATATCT
F. globosum NRRL26131             TGTGGT-CTAGGTTAGG-TACAGGGTAGGCAAGT-TCTTTC-TCCACCAGAA-ATCG-ATTGCCAACGAGATATATAGTCTAGGGTA-GGTACAGGGTAGGTAAATATCT
F. proliferatum NRRL22944         TATGGT-CTAGGTTAGG-TACAGGGTAGGCAAGT-TCTTTC-TCTACCAGAA-ATCG-ATTGGCAATGGGATATAGAGTCTAGGGTA-GGTACAGGGTAGGTAGATACCC
F. oxysporum NRRL22902            CGTGGT-TTAGGGTAGGCTCTAGGGTAAGTAGAA-TCCGAG-TTTCGTCGCCGACAG-TTTTCTG---------TGGGTGTATGGTA-GGTACAGGGTAGGCAAATCTCT
F. subglutinans MRC8553           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802           --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301          --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550          --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549          --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929               --------------------------------------------------------------------------------------------------------------
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                                       780       790       800       810       820       830       840       850       860       870       880
                                  ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331           CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum CAL2511             CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum FL2483              CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum FL2497              CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum MEX4900             CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum FL2496              CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum SA0041              CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum MEX2248             CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum SA0010              CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTKGTTTTGCCATACAAMSRAATTTTGCGGGAAATCAAAAGTGG
F. circinatum FL2472              CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum SA1834              CCTCSGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum MEX2265             CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAACGAATTTTGCGGGAAATCAAAAGTGG
F. circinatum SP5498              CCTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTCTGTGGTCTGGTGGGCGTGAGTCGA-TTTTTTGTTTTGCCATA-AAACGAATTTTGCGGGAAATCAAAAGTGG
F. subglutinans NRRL22016         ACTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTTTGTGGTCTGGCGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
F. begoniae NRRL25300             CCTCCGGCCAGTACTTGCTCGTGCGTGCGAAATGGTTTTGTGGTCTGGTGGCCGTGAGTTGATTTTTTTGTTTTGCCATAGAAATGAATTTTGCGGGAAATAAAAAGTGG
Fusarium sp. NRRL25346            CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAATGGTTTTGTGGTCTGCTGGGCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGGAAATGAAAAGTGG
Fusarium sp. NRRL25204            CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAATGGATTTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGGAAATGAGAAGTGG
Fusarium sp. NRRL26756            CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAATGGTTTTGTGGTCTGCTGGGCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATCAAAAGTGG
Fusarium sp. NRRL26757            CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAATGGTTTTGTGGTCTGCTGGGCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATCAAAAGTGG
Fusarium sp. NRRL25623            CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAATGGTTTTGTGGTCTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
Fusarium sp. NRRL25195            CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAATGGTCTTGTGGTCTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
F. succisae NRRL13613             CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAACGGTTTTGTGGCCCGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
F. anthophilum NRRL13602          CCTCCGGCCAGTACTTGCCTGTACGTGCGAAATGGTTTTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATATAAATGAATTTTGCGGGAAATCAAAAGTGG
Fusarium sp. NRRL29123            ACTCCGGCCAGTACTTGCTTATGCGTGCGAAATGGTTTTGTGGTCTGGCGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
F. bulbicola NRRL13618            CCTCCGGCCAGTACTTGCTTGTGCGTGCGAAATGGTTTTGTGGCCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAGATCAAAAGTGG
Fusarium sp. NRRL25807            CCTCCGGCCAGTACTTGCTTGTGCATGCGAAATGGTTTTGTGGTCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
Fusarium sp.  NRRL25622           CCTCCTGCCAGTACTTGTTTGTGCGTGCGAAATGGTTTTGTGGCCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
F. bacterioides NRRL20476         CTTCCGGCCAGTACTTGTTTGTGCGTGCGAAATGGTTTCAGGGCCTGGTGGGCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGGAAATCAAAAGTGG
F. pseudoanthophilum NRRL2520     TCCCCGGCCAGTACTTGCATGTGCGTGCGAAACGGTTTCGTGGTCAGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACTATCGAATTTTGCGGGAAATCAAAAGTGG
F. verticillioides NRRL22172      CCCCCGGCCAGTACTCGCATGTGCGTGCAAAACGGTTTTGTGGTCCGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACTATCGAATTTTGCGGGAATTCAAAAGTGG
F. thapsinum NRRL22045            CCCCAGGCCAGTACTTGCCCGTGCGTGCGAAATAGTTTTGCGGTCTGGTGGCCGTGAGTTGATTTTTTTGTTTTGCCGCACTATTGAATTTTGCGGGAATTCAAAAGTGG
F. concentricum NRRL25303         -ATCCGGCCAGTACTGGCCTATGCGTGCGAAATGGTTTTGCAGTCTGGTGGCCGTGAGTCGATTTTTTTGTTTCGCCATACTATTGAATTTTGCGGAAATTCAAAAGTGG
F. fractiflexum NRRL28852         -ATCCGGCCAGTACTGGCCCATGCGTGCGAAATGGTTTTGCAGTCTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACTATTGAATTTTGCGGAAATTCAAAAGTGG
F. fujikuroi NRRL13566            -ATCCGGCCAGTACTGGCCCATGCGTGCGAAATGGTTTTGCAGTCTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACTATTGAATTTTGCGGATATTCAAAAGTGG
F. globosum NRRL26131             -ATGCGGCCAGTACTGGCCCATGCGCGCGAAATGGTTTTGCAGCCTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACTATTGAATTTTGCGGAAATTCAAAAGTGG
F. proliferatum NRRL22944         -GTCCGGCCAGTACTGGCCCATGCGTGCGAAATGGTTTTGCAGTCTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACTATTGAATTTTGCGGAAATTCAAAAGTGG
F. oxysporum NRRL22902            -CTCCGGCCAGTACTT--------------------------GTCTGGTGGTCGTGAGGCGATTTTTTTGTTTTGCCATACTATTGAATTTTGCGGAAATTCAAAAGTGG
F. subglutinans MRC8553           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802           --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301          --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550          --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549          --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929               --------------------------------------------------------------------------------------------------------------
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                                           890       900       910       920       930       940       950       960       970       980       990
                                  ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331           CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum CAL2511             CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum FL2483              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum FL2497              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum MEX4900             CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum FL2496              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum SA0041              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum MEX2248             CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum SA0010              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum FL2472              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum SA1834              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum MEX2265             CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. circinatum SP5498              CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. subglutinans NRRL22016         CCCACGAGTCGGGTCTGGCGTGCGTCCGACTCGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. begoniae NRRL25300             CCCGCAAGCCGGGTCTGGCGTGCGTCCGACTGGAACATTGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
Fusarium sp. NRRL25346            CCCGCGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACACATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
Fusarium sp. NRRL25204            CCCGCGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACACATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
Fusarium sp. NRRL26756            CCTGCGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
Fusarium sp. NRRL26757            CCTGCGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
Fusarium sp. NRRL25623            CCCGCGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
Fusarium sp. NRRL25195            CCCACGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATTGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. succisae NRRL13613             CCCACGAGCCGGGTCTGGCGTGCGTCCGACTGGAACATCATCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. anthophilum NRRL13602          CCCGCGAGTCGGGTCTGGCGTGCGTCCAACTGGAACATTGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
Fusarium sp. NRRL29123            CCCACGAGTCGGGTCTGGCGTGGGTCCGACTCGAACATTGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. bulbicola NRRL13618            CCCGCGAGTCGGGTCTGGCGTGCGCCTGACTGGAACATTGTCGGTGGATATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCCGCAGGGTAGGTAAAAG
Fusarium sp. NRRL25807            CCCGCGAGTCGGGTCTGGCGTGCGTCCGACTGGAACATTGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCGTCGCGACCCGCAGGGTAGGTAAAAG
Fusarium sp.  NRRL25622           CCCGCGAGTCGGGTCTGGCGTGCGTCTGACTGGAACATTGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGACCTGCAGGGTAGGTAAAAG
F. bacterioides NRRL20476         CCAGCGAGTCGGGTCTGGCGTGCGTCTGACTGGAACATTGTCGGTGGACATATAAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCACGACCTGCAGGGTAGGTAAAAG
F. pseudoanthophilum NRRL2520     CCCGCGAGTCCGGTCTGGCGTGCGGCCGACTCGAACATCGTCGGTGGACATATGAGAGGGAGAAATCCGGCCGGGCAGGGGCCCACGCCGAGCCGCAGGGTAGGTAAAAG
F. verticillioides NRRL22172      CCCGCGAGCCCGGTCTGGCGTGCGTCCGACTCGAACACCGTCGGTGGACATATGAGAGGGAGAAATCCGGCCGGGCGGGGGCCCACGCCGAGGCGCAGGGTAGGTAAAAG
F. thapsinum NRRL22045            CCCGCGAGTCCGGTGTGGCGTGCGCCCGACTCGAACATTGTCGGTGGACATATGAGAGGAAGAAATCCGGCCGGGCAGGGGCCCACGGCGAGCCGCAGGGTAGGTAAAAG
F. concentricum NRRL25303         CCCGCGAGTCCGGTCTGGCGTGCGTCCAACTCGAACATCGACGGTAGACATATAAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGTGCCCCAGGGTAGGTAAAAG
F. fractiflexum NRRL28852         CCCGCGAGTCCGGTCTGGCGTGCGTCCGACTCAAACATCGTCGGCGGACATATGAGAGAGAGCAATCCGGCCGGGCCGGGGCCCATCGCGTGCCCCAGGGTAGGTAAAAG
F. fujikuroi NRRL13566            CCCGCGAGTCCGGTCTGGCGTGCGTCCAACTTGAACACCGTCGGTGGACACATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGTGCCTCAGGGTAGGTAAAAG
F. globosum NRRL26131             CCCGCGAGTCCGGTCTGGCGTGCGTCCAACTTGAACACCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGTGCCCCAGGGTAGGTAAAAG
F. proliferatum NRRL22944         CCCGCGAGTCCGGTCTGGCGTGCGTCCAACTTGAACACCGTCGGTGGACATATGAGAGGGAGCAATCCGGCCGGGCCGGGGCCCATCGCGTGCCCCAGGGTAGGTAAAAG
F. oxysporum NRRL22902            CTCGGGAGTCCCGCCTGGCGTGCGTCCGACTCGAACATCGTCGGTGTACATATGAGAGGGAGTAATCCGGCC-GGCCGGGGCCCATCGCGA-CTGCCGGGTAGGTAAAAG
F. subglutinans MRC8553           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512           --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802           --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301          --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867         --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550          --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549          --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602               --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929               --------------------------------------------------------------------------------------------------------------
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                                   1000      1010      1020      1030      1040      1050      1060      1070      1080      1090      1100
                               ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum CAL2511         TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum FL2483          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum FL2497          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum MEX4900         TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum FL2496          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum SA0041          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum MEX2248         TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum SA0010          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum FL2472          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum SA1834          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum MEX2265         TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. circinatum SP5498          TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTTTCTGGAGA-GGTAGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. subglutinans NRRL22016     TAAAAACAGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGA-GGTGGAAGGGCATGAAGACTTG--GACGGATCTGGTCCGGGAA
F. begoniae NRRL25300         TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTACTTAAGGAAGAGAATTGTCTGGAGA-GGTGGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
Fusarium sp. NRRL25346        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGG-GGTGGAGGGGCATGAAGACTTG--G-----------------A
Fusarium sp. NRRL25204        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGG-GGTGGAGGGGCATGAAGACTTG--GACGGATCTGGTCCGGGAA
Fusarium sp. NRRL26756        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGG-GGTGGAGGGGCATGAAGACTTG--GACGGATCTGGTCCGGGAA
Fusarium sp. NRRL26757        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGG-GGTGGAGGGGCATGAAGACTTG--GACGGATCTGGTCCGGGAA
Fusarium sp. NRRL25623        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGCAAGACAATTGTCTGCAGG-GGTGGAAGGGCATGAAGACTTG--GACGGATCTGGTCCGGGAA
Fusarium sp. NRRL25195        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGA-GGTGGAAGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. succisae NRRL13613         TAAAAA-AGTTGTTAAAAGGCCCGGTGTCGGTGTGCTTGTATCCGAGGAAGAGAATTGTCTGGAGA-GGTGGAAGGGCATGAAGACTTG--GACGGA-------------
F. anthophilum NRRL13602      TTAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGG-GGTGGAGGGGCACGAAGACTTG--GACGGATCTGGTCCGGGAA
Fusarium sp. NRRL29123        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGA-GGTGGAAGGGCATGAAGACTTG--GACGGATCTGGTCCGGGAA
F. bulbicola NRRL13618        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTTCAGA-GGTGGAAGGGCATGAAGACTTG--GACGGATCTGGTCCGGGAA
Fusarium sp. NRRL25807        TAAAAA-AGTTGATAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTTGAGA-GGTGGAAGGGCATGAAGACTCG--GACGGATCTGGTCCGGGAA
Fusarium sp.  NRRL25622       TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTCGAGGAAGAGAATTGTCTGGAGA-GGTGGAGGGGCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. bacterioides NRRL20476     TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTATCTAGAGA-GGTGGAGAGCCAGGAAGACTTG--GACGGATCTGGTCCGGGAA
F. pseudoanthophilum NRRL2520 TAGATA-AGTTGTTAAGAGGCCCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAATTGTCTGGAGG-TGGAGGACGGCCAGGAAATCCGATGTTCACCCGGGCACGGGAA
F. verticillioides NRRL22172  TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGGAAGAGAGTTGTCCGGAGG-TGGAGGGCGGCCAGGAAATCCGACGCTCACCCGGGCATGGGAA
F. thapsinum NRRL22045        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGAGAGAGAGAATTGTCTGGAGG-TGAAGGGCGGCGAGGAAATCCGATGTTCACCCGGGCATGGGAA
F. concentricum NRRL25303     TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGGGGAAGAGAATTATCTGGAGGTGGAGGGGAGCCGGGAAGACTTG--GACGGATCCGGTCTGGGAA
F. fractiflexum NRRL28852     CAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGGGGAAGAGAATTGTCTGGAGGTGGAGGGGAGCCGGGAAGACTTG--GACGGATCTGGTCTGGGGA
F. fujikuroi NRRL13566        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGGGAAAGAGAATTATGTGGAGGTGGAGGGGAGCCGGGAAGACTTG--GACGGATTCGGTCCGGGAA
F. globosum NRRL26131         TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTTGGGGAAGAGAATTGTCTGGAGGTGGAGGGGAGCCAGGAAGACTTG--GACGGATTCGGTCCGGGAA
F. proliferatum NRRL22944     TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGTGTGCTTGTATTCGGGGAAGAGAATTATCTGGAGGTGGAGGGGAGCCCGGAAGACTTG--GACGGATTCGGTCCGGGAA
F. oxysporum NRRL22902        TAAAAA-AGTTGTTAAGAGGCGCGGTGTCGGCGTGCTTGTATTTGCGGGAGAGAATTATCTGGGGGTGCTGGGTAGCCGGGAAGACTTG--GACGGATCTGGCCCGGGAA
F. subglutinans MRC8553       --------------------------------------------------------------------------GGGCATGAAAACTTG--GACGGATCTGGTCCGGGAA
F. subglutinans MRC8554       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512       --------------------------------------------------------------------------GGGCATGAAAACTTG--GACGGATCTGGTCCGGGAC
F. subglutinans MRC2802       --------------------------------------------------------------------------GGCCCCCAAAACTC---GACGGGACCTGGTCGGGGC
F. proliferatum CMW 12864     -------------------------------------------------------------GGAGGTGGAGGGAAGCCGGGAAGACTTG--GACGGATTCGGTCCGGGAA
F. proliferatum MRC 2301      -----------------------------------------------------------CTGGAGGTGGAGGGAAGCCGGGAAGACTTG--GACGGATTCGGTCCGGGAA
F. proliferatum CMW 12867     -------------------------------------------------------------GGAGGTGGAGGGAAGCCGGAAAGACCGG--GACGGATTCGGCCCGGGAA
F. proliferatum MRC 8550      -------------------------------------------------------------GGAGGTGGAGGGAAGCCGGGAAGACCGG--GACGGATTCGGTCCGGGAA
F. proliferatum MRC 8549      -------------------------------------------------------------GGAGGTGGAGGGGAGCCGGGAAGACCTG--GACGGATTCGGTCCGGGAA
F. oxysporum CAV105           -----------------------------------------------------------CGGGAGGTGCTGGGTACCCGGAAAAACTTG--AACGGATCTGGCCCGGGCC
F. oxysporum CAV617           -------------------------------------------------------TTATCTGGAGGTGCTGGGCACCCGCAAAAACTTG--GACGGATCTGGCCCGGGAA
F. oxysporum CAV794           ----------------------------------------------------------------GGTGCTGGGTACCCGGAAAAACTTG--AACGGATCTGGCCCGGAAA
F. oxysporum CAV602           ----------------------------------------------------------TCTGGGGTTGCTGGGTACCCGGAAAAACTTG--AACGGATCTGGCCGGGAAT
F. oxysporum CAV929           ------------------------------------------------------------------TGCTGGGAACCCGGAAAAACTTG--AACGGATCTGGCCCGGACC
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                                         1110      1120      1130      1140      1150      1160      1170      1180      1190      1200      1210
                                     ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331              CGGGTCTGGGCTCGGATTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum CAL2511                CGGGTCTGGGCTCGGATTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum FL2483                 CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum FL2497                 CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum MEX4900                CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum FL2496                 CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum SA0041                 CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum MEX2248                CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum SA0010                 CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum FL2472                 CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum SA1834                 CGGGTCTGGGCTCGGATTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum MEX2265                CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. circinatum SP5498                 CGGGTCTGGGCTCGGATTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. subglutinans NRRL22016            CGGGTCTGGGCTCGGGGTTTGGGGTAGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT-----------ACAGGGTAGGCACAGGGTAGGCACAGGGTAG
F. begoniae NRRL25300                CGGGTCTGGGGTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL25346               CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL25204               CAGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGATGGTC----------------------------------CAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL26756               CGGGTCTGGGCTCAGGTTTTGGGGTAGTGCAGGGTAGGCAGGTTTAGATAGACAGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL26757               CGGGTCTGGGCTCAGGTTTTGGGGTAGTGCAGGGTAGGCAGGTTTAGATAGACAGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL25623               CGGGTCTGGGCTCTGGTTTTTGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL25195               CGGGTCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. succisae NRRL13613                ----TCTGGGCTCGGGTTTTGGGGTGGTGCAGGGTAGGCAGGTTTGGATGAACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTGG
F. anthophilum NRRL13602             CGGGTCTGGGCTCGGGTTTTGGGGTAGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CCAGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL29123               CGGGCCTGGCCTCGGGTTTTGGGGCGGTGCAGGGTAGGCAGGTTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. bulbicola NRRL13618               CGGGTCCGGGCTCGGGTTTGGGGGTGGTGCAGGGTAGGCAGGCTTAGACAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp. NRRL25807               CGGGTCCGGGCTCGGGTTTGGGGGTGGTGCAGGGTAGGCAGGCTTAGATAGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
Fusarium sp.  NRRL25622              CGGGTCCGGGCTCGGGTCTTGGGGCGGTGCAGGGTAGGCAGGCTTAGATAGACAGTC-CAGGGTAGGT----------------------ACAGGGTAGGTGCAGGGTAG
F. bacterioides NRRL20476            CGGGTCTGGGCTCGGGTCTTGGGGTGGTGCAGGGTAGGCAGGCTTAGATAGACAGTC-CAGGGTAGGT----------------------ACAGGGTAGGC---------
F. pseudoanthophilum NRRL2520        CGGGTCTCGGCCCGGATTCTGGTGCGGTGCAGGGTAGGCAGCTCTATATAGGTAGTC-TAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. verticillioides NRRL22172         CGGGTTTCGGCCCGGATTCTGGTGCGGTGCAGGGTAGGCAGGTCTGTATAGATAGTC-TAGGGTAGGT----------------------ACAGGGTAGGCACAGCGTAG
F. thapsinum NRRL22045               CGGGTGTCGGCCCGGATTCCTGAGCGGTGCAGGGTAGGCAGGTCTATATAAGTGGTC-TAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. concentricum NRRL25303            CGGGTCTGGACCGGGGTTCTGGCGTGGTGCAGGGTAGGCAAGTCTGATCTGATAGTA-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. fractiflexum NRRL28852            CTGGTCTGGGCCC-GGTTTTGGCGTGGTGCAGGGTAGGTAAGTCTGATCGGATGGTC----------------------------------CAGGGTAGGCACAGGGTAG
F. fujikuroi NRRL13566               CTGGTCTGGGCCT-GGTTTTGGCGTGGTGCAGGGTAGGCAAGTCTGATCGGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCACAGGGTAG
F. globosum NRRL26131                CTGGTCTGGGCCT-GGTTTTGGCGTGATGCAGGGTAGGCAAGTCTGATCTGATGGTC-CAGGGTAGGT----------------------CCAGGGTAGGCACAGGGTAG
F. proliferatum NRRL22944            CTGGTCTGGGCCT-GGTTTTGGCGTGGTGCAGGGTAGGCAAGTCTGATCGGACGGTC-CAGGGTAGGT----------------------ACAGGGTAGGCGCAGGGTAG
F. oxysporum NRRL22902               TGGGTCTGGGCCTGGATTCTGGTGTGGTGTAGGGTAGGCGTAGGTAGATGAGTGGTC-TAGGGTAGAT----------------------ACAGGGTAGCC---------
F. subglutinans MRC8553              CGGTTTGGGGCTCGGGGTTTGGGGTAGTGCAGGGTAGGCAGGTTTAAATAGACGGTC-CAGGGTAGGTACAGGGTAGGCACAGGGTAGGCACAGGGTAGGCACAGGGTAG
F. subglutinans MRC8554              --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512              CGGGCCTGGGCTCGGGGTTGGGGGTAGTGCAGGGAAGGCGGGTTTAAATAGACGGCC-CAGGGTAGGT-----------ACAGGGTAGGCCCAGGGTAGGCACAGGGTAG
F. subglutinans MRC2802              CGGGGGGGGGCTCTGGTTTTTGGGGGGGGCGGGGTCGGCAGGTTTTTATAGCCGGGC-CGGGGTAGGT----------------------TCAGGGGAGGCACAGGCCAG
F. proliferatum CMW 12864            CGGGTGGGGGCC-GGGTTTTGGCGGGGGGCAGGGAAAACAACTTTGATCGAACGGCC-CAGGGTAGGT----------------------ACGGGGTAGGCGCAGGATAG
F. proliferatum MRC 2301             CGGGTGGGGGCC-TGGTTTTGGCGGGGGGCAGGGAAAACAAGTTTGATCAAACGGCC-CAGGGTAGGT----------------------ACGGGGTAGGCGCAGGATAG
F. proliferatum CMW 12867            -GGGCCGGGGCC-GGGTTTTGGCGGGGGGCAGGGAAGGCAACCCTAATGGGACGGCC-CAGGGTAGGT----------------------CCGGGGTAGGCGCAGGGAAG
F. proliferatum MRC 8550             CGGGGCGGGGCC-GGGTTTTGGCGGGGGGCAGGGAAGGCAAGCCTGATCGGACGGCC-CAGGGTAGGT----------------------CCGGGGTAGGCGCAGGGTAG
F. proliferatum MRC 8549             TAGGTGGGGGCC-TGGTTTTGGCGGGGTGCAGGGTAGGCAACTCTGATGGGACGGCC-CAGGGTAGGC----------------------CCGGGGTAGGCGCAGGGAAG
F. oxysporum CAV105                  TGGGGCGGGGCCGGGATTCGGGTGGGGGGTAGGATAACCATACTTAAATGAGTGGTC-T---------------------------------GGGGTACCC---------
F. oxysporum CAV617                  TGGTTCTGGGCCTGGTTTCGGGTGTGGTGTAGGATAAGCGTAAATAGATGAGTGGTC-T---------------------------------AGGGTACCC---------
F. oxysporum CAV794                  TGGTTCGGGGCCTGGTTTCTGGTGTGGTGTAGGGTAGGCTTAATTAGATGAGGGGTC-TAGGGTAGGT----------------------AGAGGGTACCC---------
F. oxysporum CAV602                  TGGCTTGGGGCCGGGATTCGGGGGGGGGTAGGGAAGGCTTAATTAGATGAGGGGTCTTAGGGTAAAT----------------------ACGGGGTACCC---------
F. oxysporum CAV929                  TGGGTCGGGCCCGGGTTTCGGGTGGGGTGTAGGGAAGGCTTAATTAAATGAGGGGTC-TAGGGTAAAT----------------------CCGGGGAACCC---------
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                                 1220      1230      1240      1250      1260      1270      1280      1290      1300      1310      1320
                             ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331      GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum CAL2511        GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum FL2483         GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum FL2497         GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum MEX4900        GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum FL2496         GTAGAAGTCC-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTCGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum SA0041         GTAGAAGTCC-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTCGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum MEX2248        GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum SA0010         GTAGAAGTCC-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTCGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum FL2472         GTAGAAGTCC-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTCGGATACCGTTTTGTTTCACGCCCTTACCTTGGYYYKRGAAGGGACAATCTTGGCCCGGGATCGAAG
F. circinatum SA1834         GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCWTRCCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum MEX2265        GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. circinatum SP5498         GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGATACCGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATCGAAG
F. subglutinans NRRL22016    GTAGAAGTTT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTCGGATACTGTTTTGTTTCACGCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATGGAGG
F. begoniae NRRL25300        GTAGAAGTCT-GGTAGATAGTATGGGCGGGTGTAGGGTAGGCTCGGACACCGTTTCGTTTTGTGCCCTTGCCTTTGCACGAGAAACGGCGATCTTGG-CCGGGATCGAGG
Fusarium sp. NRRL25346       GTAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTCGGACACCGTTTCGTTTTGTGCCCTTGCCTTTGCACGAGAAACGGCAATCTTGG-CCGGGATCGAGG
Fusarium sp. NRRL25204       GTAGAAGTCT-GGTAGATAGTATGGGCGGGTGTAGGGTAGGCTCGGACACCGTTTTGTCTTGTGCCCTTACCTTTGCACGCGAAACGACAATCTTGG-CCAGGATTGAGG
Fusarium sp. NRRL26756       GTAGAAGTCT-GGTAAATAGTATGGGCAGGTGTAGGGTAGGCTCGGACACCGTTTCGTTTTGTGCCCTTACCTTTGCACAAGAAACGACAGTCTTGG-CCAGGATCGAGG
Fusarium sp. NRRL26757       GTAGAAGTCT-GGTAAATAGTATGGGCAGGTGTAGGGTAGGCTCGGACACCGTTTCGTTTTGTGCCCTTACCTTTGCACAAGAAACGACAGTCTTGG-CCAGGATCGAGG
Fusarium sp. NRRL25623       GCAGAAGTCT-GGTAAATAGTATGGGCAGGTGTAGGGTAGGCTCGGACACCGTTTCGTTTTGTGCCCTTACCTTTGCACGAGAAACGACAATCTTGG-CCGGGATCGAGG
Fusarium sp. NRRL25195       GTAGAGGTCT-GGTAAATAGTATGAGCGGGTGTAGGGTAGGCTTGGACACCGTTTCGTTTCACGCGCTTACCTTTG--CGAGAAACGACGATCTTGG-CCGGGATGAAGG
F. succisae NRRL13613        GTAAAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGACACCGTTTTGCTTCACGCCCTTTGCTTGGCTCGAGAAACGACGATCTTGG-CCGGGATCGAGG
F. anthophilum NRRL13602     GTGGAAGTCT-GGCAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGACACCGTTTTGTTTCACGCCCTTACCTTTGCACGAGAAACGACAATCTTGG-CCGGGATGGAGG
Fusarium sp. NRRL29123       GTAGAAGTCT-GGTAAATAGTGTTGGCAGGTCTAGGGTAGGCTTGGATACTGTTTTGTTTTGCGCCCTTACCTTGGCTCGAGAAACGACGATCTTGG-CCGGGATGGAGG
F. bulbicola NRRL13618       GTAGAAGTCT-GGTAAGTAGTGCTGGCAGGTGTAGGGTAGGCCTGGACACCGTTTCGTTTTGCGCCCTAACCTTGGCTCGAGAAACGACGATCTTGG-CCGGGATGGAGG
Fusarium sp. NRRL25807       GTAGAAGTCT-GGTAAATAGTGTTGGCAGGTGTAGGGTAGGCTTGGACACCGTTTCGTTTTGCGCCCTAACCTTGGCTCGAGAAACGACGATCTTGG-CCGGGATGGAGG
Fusarium sp.  NRRL25622      GCAGAAGTCT-GGTAAATAGTATGGGCGGGTGTAGGGTAGGCTTGGACACTGTTTTGTTTCACGCCCTTACCTTGGCTCGAGGAACGACGATCTTGG-CCGGGACGGGGG
F. bacterioides NRRL20476    --AGAAGTCT-AGTAAATAGTGTGAGCGGGTGTAGGGTAGGCTTGGGCACTGTTTTGTTTTACGCCCTTACCCTGGCTTGAGAAATGACAATCTTGG-CCAGGATGGGGG
F. pseudoanthophilum NRRL2520 GTAGAAGTCT-GGTATATAGTA--GGAGGGTGTAGGGTAGGCTCAGATACCGATCCGTTTCGCGCCCTCACCTTGGCTCGAGAAGCGACGATCTTGG-CCGGGATGGAGG
F. verticillioides NRRL22172 GTAGAAGTCT-GGTATATAGTATGGGCGGGTGTAGGGTAGGCTCAGACACCGATCCGTTTCGCGCCCTCACCTTTGCTCGGAAAACGACAATCTTGG-CCGGGATGCAGG
F. thapsinum NRRL22045       GTAGAAGTATAAGTGTATAGTATGGGCGGGTATAGGGTAGGCTCAGACACTGATCCGTTTCGCGGCCTCACTTTTGCTCGAGAAACGACGATCTTGG-CCGGGATGGAGG
F. concentricum NRRL25303    GTAGAAGTCT-GGTATATAGTATGGACAGGTGTAGGGTAGGCCGAGACACCGTTTTGCTTTGCGCGCTTACCTTTGCTTGAGAAACGACGATCTTGG-CCGGAATGATGG
F. fractiflexum NRRL28852    GTAGAAGTCT-GGTAGATAGTATGGGCGGGTGTAGGGTAGGCCGAGACACTGTTTTGTTTTGCATCCTTACCTTTGCTTAAGAAACGACGATCTTGG-CCGGAAGGAAGG
F. fujikuroi NRRL13566       GTAGAAGCCT-GGTATATAGTATGGACGGGTGTAGGGTAGGCTAAGACACCGTTTTGTTTTGCGCCCTTACCTTTGCTTGAGAAACGACGATCTTGG-CCGGGATGAGGG
F. globosum NRRL26131        GTGGAAGCCT-GGTATATAGTATGGACGGGTGTAGGGTAGGCTGAGACACCGTTTTGTTTTGCGCTCTTACCTTTGCTCGAGAAACGACGATCTTGG-CTGGAATGAAGG
F. proliferatum NRRL22944    GTAGAAGCCT-GGTATATAGTATGGGCGGGTGTAGGGTAGGCTGAGATACCGTTTTGTTTTGCGCCCTTACCTTTGCTTGAGAAACGACGATCTTGG-CCGGAATGAAGG
F. oxysporum NRRL22902       --AGACGTCT-GGTATATAGTATGG--GGGTGTAGGGTAGGTCTGGACACCGTTTTCCACTTCGCCCTTCCCTTTAGTCGAGGGAGGACGATCTTGG-CTGGGACGGAGG
F. subglutinans MRC8553      GTAAAATTTT-GGTAAATAGTAGGGGCGGGTGTAGGGTAGGCTCGGATACTGTTTTGTTTCACCCCCTTACCTTGGCTCGAGAAGGGACAATCTTGG-CCGGGATGGAGG
F. subglutinans MRC8554      ------------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512      GTAGAATTTT-GGTAAATAGTATGGGGGGGTGTGGGGTAGGCTCGGATCCTGTTTTGTTTCACCCCCTTCCCTTGGCTCGAAAAGGGACAATCTGGC-CCGGGATGGAGG
F. subglutinans MRC2802      CAAAAACCCC-GGTAAAC-CCGTGGGGGGGTGTAGGGAAGGCTCGAAAGGGCTTCCTTTTGGAGCCTTTACCTTTGAAAAAGAAAGGGGTTTTTTGC-CCGGTTTCCCGG
F. proliferatum CMW 12864    GTAAAACCCG-GGTATATAGTAGGGGGGGGTGTAGGGTAGGCTGAAATACCTTTTTGTTTTGCCCCCTTACTTTTGTTTGAAAAACGACAATTTTGG-CCGGAATGAAGG
F. proliferatum MRC 2301     GTAAAACCCT-GGTATATAGTAGGGGGGGGTGTAGGGTAGGCTGAAATACCGTTTTGTTTTGCCCCCTTACTTTTGTTTGAAAAACGACAATTTTGG-CCGGAATGAAGG
F. proliferatum CMW 12867    GTAAAACCCG-GGTATATAGTAGGGGGGGGTGTAGGGAAGGCTGAAATACCGTTTTGTTTTGCCCCTTTACTTTTGCTTGAAAAACGACAATTTTGG-CCGGAATGAAGG
F. proliferatum MRC 8550     GTAAAACCCG-GGTATATAGTAGGGGGGGGTGTAGGGTAGGCTGAAATACCGTTTTGTTTTGCCCCTTTACTTTTGCTTGAAAAACGACAATTTTGG-CCGGAATGAAGG
F. proliferatum MRC 8549     GTAGAACCCG-GGTATATAGTAGGGGGGGGTGTAGGGAAGGCTGAAATACCGTTTTGTTTTGCCCCCTTACTTTTGCTTGAAAAACGACAATTTTGG-CCGGAATGAAGG
F. oxysporum CAV105         --AAAATTCT-GGTTTATGGTA-GGGGGGGTGTTGGGTAGGTCGGGACACCGTTTTCCAATTCCCCC------TTACCCGAGGGAGGACAATCTTGG-CTGGTTTGGAGG
F. oxysporum CAV617         --AAAATTCT-GGTATATAGTA-GGGGGGGTGTAGGGTAGGTCTGGACACCGTTTTCCATTTCCCCCTTCCTTTTACTCGAGGGAGGACAATCTTGG-CTGGAATGGAGG
F. oxysporum CAV794         --AAAATTCT-GGTACATATTA--GGGGGGTGTAGGGTAGGTCTGGACACCTTTTTCTACTTCCCCTTTCCTTTTACTCGAGGGAGGACAATTTTGG-TTGGAATGGAGG
F. oxysporum CAV602         --AGACTTCG-GGTATATATTA--GGGGGGTGTGGGGTAGGTCTGGACACCTTTTTCCATTTCCCCTTTCCTTTTATTCAAGGGAGGACAATTTTGG-TGGGAACGGAGG
F. oxysporum CAV929         --AAACTTCG-GGTTTTTATTT--GGGGGGTGTAGGGAAGGTCTGGACCCCTTTTCCCATTTCCCCCTTCCTTTTATTCAAGGAAGGACAATTTTGG-CGGGAACGGAGG
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                                      1330      1340      1350      1360      1370      1380      1390      1400      1410      1420      1430
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F. circinatum NRRL25331       TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum CAL2511         TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum FL2483          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum FL2497          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum MEX4900         TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum FL2496          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum SA0041          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum MEX2248         TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum SA0010          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum FL2472          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum SA1834          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum MEX2265         TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. circinatum SP5498          TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. subglutinans NRRL22016     TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. begoniae NRRL25300         TCTAGGGTAGGCTGAATCTATGATTATGTAAGCTGTGCTACTCTAGGGTAGGTAAAAATTCCATATAAATCTGATTGGAATTGGTGAAGATATGATTTGGCTGGAGAGAT
Fusarium sp. NRRL25346        TCTAGGGTAGGCTGAATCTATGATTATGTAAGCTGTGCTACTCTAGGGTAGGTTAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
Fusarium sp. NRRL25204        TCTAGGGTAGGCTGAATCTATGATTATGTAAGCTGTGCTACTCTAGGGTAGGTAAAAATCCCATATAAATCTGATCGGAATTGGTGAAGATGCGATTTGGCTGGAGAGAT
Fusarium sp. NRRL26756        TCTAGGGTAGGCTGAATCTATGATCATGTAAGCTGTGCTACTCCAGGGTAGGTAAAAATCCCATACAAATCTGATCGGAATTGGTGAGGATGTGATTTGGCTGGAGAGAT
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Fusarium sp. NRRL25623        TCTAGGGTAGGCTGAATCTATGATTATGTAAGCTGTGCTACTCTAGGGTAGGTGAAAATCCCATACAAATCTGATCGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
Fusarium sp. NRRL25195        TCTAGGGTAGGCTGATTTTATGATTATGTAAGCTGTACTACTCTAGGGTAGGTGAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATGTGATTTGGTTGGAGAGAT
F. succisae NRRL13613         TCTAGGGTAGGCTGAATTTATGATTATGCAAGCTGTATAGCTCTAGGGTAGGTAAAAATCCCATACAAATCGGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. anthophilum NRRL13602      TCTAGGGTAGGCTGAATCCATGATTATGTAAGCTGTATAACTCTAGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAGATATGATTTGGCTGGAGAGAT
Fusarium sp. NRRL29123        -----------------------------------------TCTAGGGTAGGTGAAAATCCCATACAAATCTGATCGGAATTGGTGAAGATCTGATTTGGCTGGAGAGAT
F. bulbicola NRRL13618        TCTAGGGTAGGCTGATTTTATGATTGTGTACGCTACATTACTCTAGGGTAGGTGAAAATCTCACATAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
Fusarium sp. NRRL25807        TCTAGGGTAGGCTGATTTTATGATTATGTAAGCTACATTACTCTAGGGTAGGTGAAAATCTCATATAAATCTGATTGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
Fusarium sp.  NRRL25622       TCTAGGGTAGGCTAAATATGTGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAATCTCATACAAATCTGATCGGAATTGGTGAAGATGTGATTTGGCTGGAGAGAT
F. bacterioides NRRL20476     TCTAGGGTAGGCTGAATCTGTGATTGTGTAAGCTGTATAGCTCTAGGGTAAGTGAAAATCTTATATAAATCTGATTGGAATTGGTAAAGATGTGATTTGGCTGGAGAGAT
F. pseudoanthophilum NRRL2520 TCTAGGGTAGGCTGGATTCATGATTACATAAGCTGTACTGCTCTAGGGTAGGTGAAGACCCCATACAAATCTGATCAGAAACGGTGAAGAAGTGATTTTGCTCGGGAGAT
F. verticillioides NRRL22172  TCTAGGGTAGGCTGAATCTATGATTATATAAGCTATACTGCTCTAGGGTAGGTGAAGATCCCATAGAAATCTGATCAGAATTGGTGACGAAGTGATTTTGCTCGGAAGAT
F. thapsinum NRRL22045        TCTAGGGTAGGCTGAATTTATGATTATATAAGCTGTATTACTCTAGGGTAGGTGAAAATCCCGTATAAGTCTGACCAGAACTGGTGAAGATGTGATTTTGCTCGGAAGAT
F. concentricum NRRL25303     TCTAGGGTAGGCTGAATTTATGATTATATAAGCTGGATAGCTCTAGGGTAGTTGAAAATTCCATACAAATCTGGTTGCAATTGGTGAAGTTGTGATTTTGCTGTGAAGAT
F. fractiflexum NRRL28852     TCTAGGGTAGGCTGAATCTATGATTAGATAAGCTAGATTACTCTAGGGTAGGTGAAAATCCGATATAAATCTGGTTGCAATTGGTGAAGTTGTGATTTTGCTGTGAAGAT
F. fujikuroi NRRL13566        TCTAGGGTAGGCTGAATCTATAATTGTATAAGCTAGACTACTCTAGGGTAGGTGAAAATCCCATCTAAATCTGGTTGCAATTGGTGAAGTTGTGATTTTGCTGTGAAGTT
F. globosum NRRL26131         TCTAGGGTAGGCTGAATTTATGATTATATAAGCTGGATAGCTCTAGGGTAGTTGAATATCCCATACAAATCTGGTTGCAATTGGTGAAGTTGTGATTTTGCTGTGAAGAT
F. proliferatum NRRL22944     TCTAGGGTAGGCTGAATTTATGATTATATAAGCTGGATAGCTCTAGGGTAGTTGAAAATCCCATACAAATCTGGTTGCAATTGGTGAAGTTGTGATTTTGCTGTGAAGAT
F. oxysporum NRRL22902        TGTAGGGTAAGCTTAATTTACGATTACATGATCTGTGTCACTCTAGGGTAGGTGAAAATCCCATATATATCTGATCACATTTGGTGAAGAGGTGGTTTGGCTGGTGAGAT
F. subglutinans MRC8553       TCTAGGGTAGGCTGAATGTATGATTATGTAAGCTGTATAGCTCTGGGGTAGGTAAAAATCCCATACAAATCTGATTGGAATTGGTGAAAATGTGATTTGGCTGGAGAGAT
F. subglutinans MRC8554       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512       TCTAGGGTAGGCTAAATGTTTGATTATGTAAGCTGTATAGCTCTAGGGTAGGTAAAAACCCCATACAAATCTGATTGAAATTGGGGAAAATGTGATTTGGCTGGARAGAT
F. subglutinans MRC2802       CCCCGGTTAGGGTGAGCCTGGATTTATTCCCTCTGTGTTACCCTGGGGAAGGGGAAAATCCGGGCCAAACCCAAAAGGAATTGGGGGGGATGTTTTTTGTTTGCCGAAAT
F. proliferatum CMW 12864     TCTAGGGTAGGTTGATTTTATGATTATATAAGCTGGATAGCTCTAGGGAAGTTAAAAATCCCATACAAATCTGGTTGCAATTGGGGAATTTGTGATTTTGCTGTGAAAAT
F. proliferatum MRC 2301      TCTAGGGTAGGCTGATTTTATGATTATATAAGCTGGATAGCTCTAGGGTAGTTGAAAATCCCATACAAATCTGGTTGCATTTGGTGAATTTGTGATTTTGCTGTGAAAAT
F. proliferatum CMW 12867     TCTAGGGTAGGTTGATTTTATGATTATATAAGCTGGATAGCTCTAGGGAAGTTAAAAATCCCATACAAATCTGGTTGCAATTGGTGAAGTTGTGATTTTGCTGTGAAAAT
F. proliferatum MRC 8550      TCTAGGGTAGGTTGATTTTATGATTATATAAGCTGGATAGCTCTAGGGTAGTTAAAAATCCCATACAAATCTGGTTGCAATTGGTGAATTTGTGATTTTGCTGTGAAAAT
F. proliferatum MRC 8549      TCTAGGGTAGGTTGATTTTATGATTATATAAGCTGGATAGCTCTAGGGAAGTTAAAAATCCCATACAAATCTGGTTGCAATTGGTGAATTTGTGATTTTGCTGTGAAAAT
F. oxysporum CAV105           TGTTGGGTAGGCTTAACTTACAATTACTTTTTCTGTGTCACTCTAGGGAAGGGGAAAATCCCATATATATCTGATCACATTTGGTGAAGAGGTGGTTTGGCTGGTGAGAT
F. oxysporum CAV617           TGTAGGGTAGGCTTAATCTACAATTACTTGATCTGTGTCACTCTAGGGTAGGTGAAAATCCCATATATTTCTAATCACTTTTGGTGAAAAGGTGGTTTGGCTGGTGAAAT
F. oxysporum CAV794           TGTAGGGTAGGTTTATTTTACAATTACTTGATCTGTGTCACTCTAGGGTAGGTAAAAATCCCATATATTTCTAATCACTTTTGGGGAAAAGGTGGTTTGGCTGGTGAAAT
F. oxysporum CAV602           TGTAGGGTAGGTTTATTTTACAATTACTTGATCTGTGTCACTCTAGGGAAGGTGAAAATCCCATATATTTCTAATCACTTTTGGGGAAAAGGTGTTTGGGTTGGGGGAAT
F. oxysporum CAV929           TGTAGGGAAGGCTTACTTTACAATTACTTGATCTGGGCCACTCTGGGGTAGGTAAAATCCCCATATTTTTTTGACCCCTTTTGGGGAAAAGGTGTTTTGCCTGGGGAAAT
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                                        1440      1450      1460      1470      1480      1490      1500      1510      1520      1530      1540
                               ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331        GGACGAAAGTGCAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAGATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum CAL2511          GGACGAAAGTGCAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAGATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum FL2483           GGACGAAAGTGCAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAGATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum FL2497           GGACGAAAGTGCAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAGATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum MEX4900          GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGKATGC
F. circinatum FL2496           GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum SA0041           GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum MEX2248          GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum SA0010           GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGM
F. circinatum FL2472           GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum SA1834           GGACGAAAGTGCAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAGATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGATGC
F. circinatum MEX2265          GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTCAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCGGAWGC
F. circinatum SP5498           GGACGAAAGTGCAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAGATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATTGGATGC
F. subglutinans NRRL22016      GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCAGAGCAGGTAAGAGCACGTTTGAGACGTCATCGGATGC
F. begoniae NRRL25300          GGAGAAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCAGATGAGAGCACGTTTGATACGTCATCCGATGC
Fusarium sp. NRRL25346         GGAGAAAAGTGTAATGCAGAGCTGTATGTGATTTTGTAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCAGATGAGAGCACGTTTGATACGCCATCAGATGG
Fusarium sp. NRRL25204         GAAGAAAAGTGTAATGCAGAACTGTGTGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCGGATGAGAGCACGTTTGATACGTCATCAGATGC
Fusarium sp. NRRL26756         GGAGAAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCAGATGGGAGCACGTTTGATACGTCATCAGATGC
Fusarium sp. NRRL26757         GGAGAAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCAGATGGGAGCACGTTTGATACGTCATCAGATGC
Fusarium sp. NRRL25623         GGAGAAAAGTGTAATGCAGAGCTGTATGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCAGATGAGAGCACGTTTGATACGTCATCAGATGC
Fusarium sp. NRRL25195         GGAGGAAAGTGTAGTGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTTAAAATG-GAAAGTCGATGTTCCCGAGCAGTTGGGAGCACGTTTGATACGTCATCCGATGC
F. succisae NRRL13613          GGATAAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCAGGTGAGAGCACGTTTGAGACGTCATCAGACGC
F. anthophilum NRRL13602       GGAGGAAAGTGCAATGCAGAACTGTATGTGATTTTGCAAAACTGAGTGTGAAAATG-GAAAGTCAATGTTCCCGAGCAGGTGAGAGCACGTTTGAGATGTCATCAGATGC
Fusarium sp. NRRL29123         GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCGGATGAGAGCACGTTTGATACGCCATCAGATGC
F. bulbicola NRRL13618         GGATAAAAGTGTGATGCAGAACTGTGTGTGATTTTGCAAAAGTGAGTGCGAAAATG-GAAAATCAATGTTCCCGAGCAGGCGAGAGCACGTTTGAGACGTCATCAGATGC
Fusarium sp. NRRL25807         GGATAAAAGTGCAGCGCAGAACTGTATGTGATTTTTCAAAAGTGAGTGCGAAAATG-GAAAGTTAATGTTCCTGAGTAGGTAAGAGTACGTTTGAGACGTTATTAGATGC
Fusarium sp.  NRRL25622        GGAGAAAAGTGTGATGCGAAACTGTATGTGATTTTGCAAAAGTGAGTATGAAAATG-GAAAGTCGATGTTCCCGAGCAGCTGAGAGCACGTTTGAGACGTCATCGGATGC
F. bacterioides NRRL20476      GGAGGAAAGTGTAATGCGGAACTGTATGTGATTTTGCAAAAGTGGGTGTGAAAATG-GAAAGTCGATGTTCCCGAGCGGGCGAGAGCACGTTTGAGACGTCATCGGATGC
F. pseudoanthophilum NRRL2520  GCAGAAAAGTGTGATGCAGAACTGTATGTGACTTTGCAAAAGTGAGTGCGAAATTG-GAAAGTCGGACTTCCCGAGCAGATGGGAGCACGTTCGAGATGTCATCGGATGC
F. verticillioides NRRL22172   GCAGAAAAGTGTAACGCAGAACTGTATGTGGCTTTGCAAAAGTGAGTGCGAAATTG-AAAAGTCGGACTTCCCGAGCGGGTGGGAGCACGTTTGAGACGTCATCGGATGC
F. thapsinum NRRL22045         GGAAATAAGTGTGATGTGGAAATGTATGTGACTTTGTAAAAGTGAGTGTGAAATTG-GAAAGTCAGACTTCCCGAGCAGATGGAAGCACGTTTGAGACGTCGTCAGATGC
F. concentricum NRRL25303      GAAGAAAAGTGTAATGCGGAATCGTATGTGACTTTCCAAAGATGGGTGTGAAATTG-GAAAGTCGGGTTTCCTGAGACGATGTGGGCACGTTTGAGACGTCATCAGATGC
F. fractiflexum NRRL28852      GGAGAAAAGTGTGATGCGGAATTGTATGTGACTTTGTAAAAGTGGGTGTGAAATTG-GAAAGTCGGGTTTCCCGAGCAGATGTGGGCACGTTTGAGACGTCATCAGATGC
F. fujikuroi NRRL13566         GGAGAAAAGTGTAATGTGGAATTGTATGTGACTTTGCAAAGGTGGGTGTGAAATTG-GAAAGTCGGTCTTCCCGAGCAGATGTGGGCACGTTCGAGACGCCATCAGATGC
F. globosum NRRL26131          GGAGAAAAGTGTGATGCAGAATTGTATGTGACTTTGCAAAAGTGGGTGTGAAATTG-GAAAGCTGGCCTTCCCGAGCAGATGTGGGCACGTTTGAGACGTCATCAGATGC
F. proliferatum NRRL22944      GGAGAAAAGTGTGACGCAGAATTGTATGTGACTTTGTAAAAGTGGATGTGAAATCG-GAAAGTCGGGTTTCCCGAGCAGATTTGGGCACGTTTGGGACGTCACCAGATGC
F. oxysporum NRRL22902         GGACAAAAGTGCAATGTAGAATTATATGTGATTTTGCAAAAGTGGGTGTGAAATTG-GAAAGTCGGTTTTCCCGCACAGATGAGAGCACGTTTGAGGTGCCATGAGATGC
F. subglutinans MRC8553        GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCCGAGCAGGTAAGAGCACGTTTGAGACGTCATCGGATGC
F. subglutinans MRC8554        --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512        GGACGAAAGTGTAATGCAGAACTGTATGTGATTTTGCAAAAGTGAGTGTAAAAATG-GAAAGTCGATGTTCCAGAGCAGGTAAGAGCACGTTTGAGACGTCATCGGATGC
F. subglutinans MRC2802        GGAGAAAAGTGTAATGCAGAGCTGTATGTGATTTTGCAAAAGTGAGTGTGAAAATG-GAAAGTCGATGTTCCCGACCAGATGAGAGCACGTTTGATACGTCATCAGATGC
F. proliferatum CMW 12864      GGAAAAAAGTGTGATGCAAAATTGTAGGTGACTTTGTAAAAGGGAATGTAAAATTG-GAAAGTCGGGTTTCCCGAGCAAATTTGGGCACTTTGGGAACGTCCCCAAATGC
F. proliferatum MRC 2301       GGAAAAAAGTGTGATGCAAAATTGTAGGTGACTTTGTAAAAGGGGATGTAAAATTG-GAAAGTCGGGTTTCCCGAGCAAATTTGGGCACKTTTGGRACGTCMCCARATGC
F. proliferatum CMW 12867      GGAAAAAAGTGGGACCCAAAATTGTTTGTGATTTTGTAAAAGGGAATGTAAAATTG-GAAAGTCGGGTTTCCCGAGCAGATTTGGGCACTTTGGGAACGCCCCCAAATGC
F. proliferatum MRC 8550       GGAAAAAAGTGTGACCCAAAATTGTTTGTGATTTTGTAAAAGGGAATGTAAAATTG-GAAAGTCGGGTTTCCCGAGCAAATTTGGGCACTTTGGGAACGTCCCCAAATGC
F. proliferatum MRC 8549       GGAAAAAAGTGTGACCCAAAATTGTTTGTGATTTTGTAAAAGGGAATGTAAAATTG-GAAAGTCGGGTTTCCCGAGCAAATTTGGGCACTTTTGGAACGTCCCCAAATGC
F. oxysporum CAV105            GGACAAAAGTGCAATGTAGAATTATATGTGATTTTGCAAAAGTGGGTGTGAAATTG-GGAAATCGGTTTTCCCGCACAGATGAGAGCACGTTTGAGGTGCCATGAGATGC
F. oxysporum CAV617            GGATAAAAGTGCACCGTAAAATTATTTGTGATTTTGCAAAATTAGGTGTAAAATTG-GGAAATCGGTTTTCCCGCACAGATGAGAGCACGTTTGAGGTGCCATGAGATGC
F. oxysporum CAV794            GGACAAAAGTGCATTGTAAATTTATTTGTGATTTTGCAAAAGTGGGTGTAAAATTG-GAAAATCGTTTTTCCCGCACAGATGAGAGCACGTTCGAGGTGCCATGAGATGC
F. oxysporum CAV602            GAACAAAAGTGAATTGTAAAATTATTTGTGATTTTGCAAAAGGGGGTGTAAATTTGAGAAAGTCGGTTTTCCCGCACAGATGAGAGCAAGTTTGAGGTGCCATGAGATGC
F. oxysporum CAV929            GAACAAAAGTGCAATATAAATTTTTTTGTGTTTTTGCAAAAGGGGGGGTAAATTGG-GAAAATCGGTTTTTCCGCACAGATGAGAGCACGTTTGAGGTGCCATGAGATGC
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                                                   1550      1560      1570      1580      1590      1600      1610      1620      1630      1640      1650
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F. circinatum NRRL25331                       GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum CAL2511                         GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum FL2483                          GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum FL2497                          GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum MEX4900                         GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum FL2496                          GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum SA0041                          GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum MEX2248                         RCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum SA0010                          RCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum FL2472                          GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum SA1834                          GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum MEX2265                         RCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. circinatum SP5498                          GCCTTGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. subglutinans NRRL22016                     GCCTCGTCTTGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAGGGGAGAGGTGTAGGGTAGGTCGTCA
F. begoniae NRRL25300                         GCCTTGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAATGTAGTGGTGTAGGGTAGGTCGTCA
Fusarium sp. NRRL25346                        GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGTAGTGGTGTAGGGTAGGTCGTCA
Fusarium sp. NRRL25204                        GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGTAGTGGTGTAGGGTAGGTCGTCA
Fusarium sp. NRRL26756                        GCCTCGTCGAGACGAGCACAAGGGTGTAGCCCATGCGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGGAGTGGTGTAGGGTAGGTCGTCA
Fusarium sp. NRRL26757                        GCCTCGTCGAGACGAGCACAAGGGTGTAGCCCATGCGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGGAGTGGTGTAGGGTAGGTCGTCA
Fusarium sp. NRRL25623                        GCCTCGTCGAGACGAGCAGAACGGTGTAGCCAATGTGTGTGCACGACTCCT-GTGCGTCCGTCCGGGGCGGGATAAGTAGA-GAAGTGAGAGGTGTAGGGTAGGTCGTCA
Fusarium sp. NRRL25195                        GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCTGTCCAGGGCGGGATAAGTAGA-AAAGGGAGAGGTGTAGGGTAGGTCGTCA
F. succisae NRRL13613                         GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGTGTCCGTCCGGGGCGGGATAAGTAGA-AAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. anthophilum NRRL13602                      GCCTCGTCGAGCCGAGCACAACGGTGTAGCCCACGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGTAGTGGTGTAGGGTAGGTCGTCA
Fusarium sp. NRRL29123                        GCCTCGTCGAGGCGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCGAGGGCGGGATAAGTAGA-AAAGGTAGTGGTGTAGGGTAGGTCGGCA
F. bulbicola NRRL13618                        GCCTCGTCGAGATGAGCACAGCGGTGTAGCCCATGTGTGTGCACGACCCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGAAGTGGTGTAGGGTAGGTAGTCA
Fusarium sp. NRRL25807                        GCCTCGTCGAGATGAGCACATCGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGTAGTGGTGTAGGGTAGGTAGTCA
Fusarium sp.  NRRL25622                       GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGCGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGTAGTGGTGTAGGGTAGGTAGTCA
F. bacterioides NRRL20476                     GCCTCGTCGAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAAGGTAGTGGTGTAGGGTAGGTCGTCA
F. pseudoanthophilum NRRL2520                 GCCTCGTCGAGACGAACACAACGGTATAGCCCACGCGTCTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAATGCAGAGGTATAGGGTAGGTAGTCA
F. verticillioides NRRL22172                  GCCTCATCGAGACGAGCACAACGGTATAGCCCACGTGTCTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGAGAGGTGTGGAGGTATAGGGTAGGTAGTCA
F. thapsinum NRRL22045                        GCCTCGCCGAGACGATCACAACGGTATAGCCCATGTGTGTGCACGATGCCT-GTGTGCCCGTCGAGGGCGGGATAAGTAGA-AAATGCAGAGGTATAGGGTAGGCAGTCA
F. concentricum NRRL25303                     GCCTTTTCGAGGCGGTCACAACGGTGCAGCTTATGTATGTGCCGGACTCCT-GTTTGTCCGTCCAGGGCGGGATAAGTAGA-AATTGATGTGGTATAGGGTAGGTCGTCA
F. fractiflexum NRRL28852                     GTCTTTTCGAGGCGGTCACAGCGGTGCAGCTTGTGTGCGTGCCAGACTCCT-GTGTGTCCCTGTACGGCGGGATAAGTAGA-AATTGAAGTGGTATAGGGTAGGTCGTCA
F. fujikuroi NRRL13566                        GCCTTTTCGAGACGGTCACAACGGTGCAGCTTATGTGTGTGCCAGACTCCT-GTGTGCCCGTCCAGGGCGGGATAAGTAGA-AATTGAAGTGGTATAGGGTAGGTCGTCA
F. globosum NRRL26131                         GCCTTTTCGAGGCGGTCACGACGGTGCAGCTTATGTGTGTTCCGGACTCCT-GTGTGTCCGTCCAGGGCGAGATAAGTAGA-AATTGAAGTGGTATAGGGTAGGTCATCG
F. proliferatum NRRL22944                     GCCTTTTCGAGGCGGTCACAACGGTGCAGCCCATGTGTGTGCCGGACTCCT-GCGTGTCTGTCTAGGGCGGGATAAGTAGA-AATTGAGGTGGTATAGGGTAGGTCGTCA
F. oxysporum NRRL22902                        ACCTCTCCGAGACGACCTCAACGGTACCACCCATGTGTTGGTCGGGCTCCT-GTGCGGCCGTCCAGGGCGGGATAAGTAGA-GAGTGTGGTGGTGTAGGGTAGGTGACCA
F. subglutinans MRC8553                        GCCTCGTCAAGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAGGGGAGAGGTGTAGGGTAGGTCGTCA
F. subglutinans MRC8554                        -----GTCTTGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAGGGGAGAGGTGTAGGGTAGGTCGTCA
F. subglutinans MRC6512                        GCCTCGTCTTGACGAGCACAACGGTGTAGCCCATGTGTGTGCACGACTCCT-GTGCGTCCGTCCAGGGCGGGATAAGTAGA-AAGGGGAGAGGTGTAGGGTAGGTCGTCA
F. subglutinans MRC2802                        GCCTTGTCGAGACGAGCAGAACGGTGTAGCCAATGTGTGTGCACGACTCCT-GTGCGTCCGTCCGGGGCGGGATAAGTAGA-GAAGTGAGAGGTGTAGGGTAGGTCGTCA
F. proliferatum CMW 12864                      CCYTTTTCRAGGCGGTCACAACGGKGCASCCCATGTGTGTGCCGGACTCCT-GCGTGTCCGTCTAGGGCGGGATAAGTAGA-AATTGAGGTGGTATAGGGTAGGTCGTCA
F. proliferatum MRC 2301                       GCCTTTTCRAGGCGGTCACAACGGKGCASCCCATGTGTGTGCCGGACTCCT-GCGTGTCCGTCTAGGGCGGGATAAGTAGA-AATTGAGGTGGTATAGGGTAGGTCGTCA
F. proliferatum CMW 12867                      CCTTTTTCAAGGSGGTTATAAKGGKGCAGYTTATGTGTGTGCCGGATTCCT-GCGTGTCCGTCTAGGGCGGGATAAGTAGA-AATTGAGGTGGTATAGGGTAGGTCGTCA
F. proliferatum MRC 8550                       CCCTTTTCRAGGSGGTTATAAKGGKGCASYTTATGTGTGTGCCGGATTCCT-GCGTGTCCGTCTAGGGCGGGATAAGTAGA-AATTGAGGTGGTATAGGGTAGGTCGTCA
F. proliferatum MRC 8549                       CCYTTTTCRAGGSGGTTATAAKGGKGCASYTTATGTGTGTGCCGGATTCCT-GCGTGTCCGTCTAGGGCGGGATAAGTAGA-AATTGAGGTGGTATAGGGTAGGTCGTCA
F. oxysporum CAV105                           ACCTCTTTGAGACGACCTCAACGGTACCACCGATGTGTTGGTCGGGCTCCT-GTGCGGCCGTCCAGGGCGGGATATGTAGA-GAATGTGGTGGTGTAGGGTAGGTGGCCA
F. oxysporum CAV617                           ACCTTTCCGAGACGACCTCAACGGTACCACCGATGTGTTGGTCGGGCTCCT-GTGCGGCCGTCCAGGGCGGGATATGTAGA-GAATGTGGTGGTGTAGGGTAGGTGGCCA
F. oxysporum CAV794                           ACCTCTCCGAGACGACCTCAACGGTACCACCGATGTGTTGGTCGGGCTCCT-GTGCGGCCGTCCAGGGCGGGATATGTAGA-GAATGTGGTGGTGTAGGGTAGGTGGCCA
F. oxysporum CAV602                           ACCTCTCCGAGACGACCTCAACGGTACCACCCATGTGTTGGTCGGGCTCCT-GTGCGGCGGTCCAGGGCGGGATAAGTAGA-GAATGTGGTGGTGTAGGGTAGGTGACCA
F. oxysporum CAV929                           ACCTTTTCGAGACGACCTCAACGGTACCACCCATGTGTTGGTCGGGCTCCTGGTGCGGCCGTCCAGGGCGGGATAAGTAGA-GAATGTGGTGGTGCAGGGTAGGTGACCA
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                                           1660      1670      1680      1690      1700      1710      1720      1730      1740      1750      1760
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F. circinatum NRRL25331            CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum CAL2511              CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum FL2483               CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum FL2497               CACCCCCGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum MEX4900              CACCCMCGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum FL2496               CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum SA0041               CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum MEX2248              CACCCCCGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum SA0010               CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum FL2472               CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum SA1834               CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum MEX2265              CACCCCCGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGTCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. circinatum SP5498               CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. subglutinans NRRL22016          CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. begoniae NRRL25300              CACCCACGATCCGATCACCTCGTCCGTCGATCCGCCTTGAGAT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp. NRRL25346             CACCCACGATCCGATCACCGCGTCCGTCGATTCGCCTTGATAT-----------GCGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp. NRRL25204             CACCCACAATCCGATCACCTCGTCCGCCGATTCACCTTGATAT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp. NRRL26756             CACCCACGATCCGATCACTTCGTCCGTCGATTCGCCTTGATAT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp. NRRL26757             CACCCACGATCCGATCACTTCGTCCGTCGATTCGCCTTGATAT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp. NRRL25623             CACCCACGACCCGATCACCTCGTCCGTCGATTCGCCTTGAGAT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp. NRRL25195             CACCCACGATCCGATCACCTCGTCCGTCGATTCGACTTTATCT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGTAACTTCCAACTT
F. succisae NRRL13613              CACCCACGACCCGATCACCTCGTCCGTCGATTCGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAGCTTCCAACCT
F. anthophilum NRRL13602           CACCCACGATCCGATCACCTCGTCCGTCGATTCGCGCTGGTAT-----------GTGAGGCAGGTCTAGGGTAGGTTAAAGTCAGGTCTAGGGTAGGCAGCTTCCAACCT
Fusarium sp. NRRL29123             CACCCACGATCCGATCACCTCGTCCGTCGATTCGCCTTGATAT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGCCAGGTCTAGGGTAGGCAACTTCCAACCT
F. bulbicola NRRL13618             CACCCACGGTCGGATCACCTCGTCCGTCGATTCGCCTTTATCT-----------GTTGGACAGGTCTAGGGTAGGCCAGAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp. NRRL25807             CACCCACGGTCGGATCACCTCGTCCGTCGATTCGCCTTTATCT-----------GTTGGACAGGTCTAGGGTAGGCCAGAATCAGGTCTAGGGTAGGCAACTTCCAACCT
Fusarium sp.  NRRL25622            CACCCACGACCCGATCACCTCGTCCGTCGATTCGCCTTTGTTC-----------GTTGGACAGGTCTAGGGTAGGCCAGAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. bacterioides NRRL20476          CACCTACGATCCGATCACCTCGTCCGTCGATTCGTCTTGATAT-----------GTGAGA----------------------CAGGTCTAGGGTAGGCAACTTCGAACCT
F. pseudoanthophilum NRRL2520      CACCCACGACCCGCTCACCTCGTCCGTCGATTCGTCTTCAAAT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCGGGTCTAGGGTAGGCAACTTCCCACCT
F. verticillioides NRRL22172       CACCCACGA-CCGTTCACCTCGTCCGTCGATTCGTCCTCATAT-----------GCGGGACAGGTCTAGGGTAGTCCAGAGTCGGGTCTAGGGTAGGCAACTTCCCACCT
F. thapsinum NRRL22045             CACCCACGACGCGTTCACCTTGTCTGTCGATTCGTCTTCAATTCGTCTTCAAGAGTGAGACTGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACCTCTCACCT
F. concentricum NRRL25303          TACCCACAGTCGATTCACCTCGCCCGTCGATTCGCCTTGGGTT-----------GAGGGACAGGTCTAGGGTAGGCCAGAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. fractiflexum NRRL28852          CACCCATGGTCGAATCACCTTGCCCGTCGATTCGCCTTGAGGT-----------GAGGTACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTTCAACCT
F. fujikuroi NRRL13566             CACCCACGGTCGACTCACCTCGCCCGTCGATTCGCCTTGGGTT-----------GAGGGACAGGTCTAGGGTAGGCCAGAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. globosum NRRL26131              CACCCACAGTCGATTCACCTCGCCCGTCGATTCGCCTTGAGGT-----------GAGGGACAGGTCTAGGGTAGGCGAAAGTCGGGTCTAGGGTAGGCAACTTCCAACCT
F. proliferatum NRRL22944          CACCCACGGTCGAATCACCTCGCCCGTCGATTCGCCTTGAGGT-----------GAGGGACAGGTCTAGGGTAGGCAGAAGTCGGGTCTAGGGTAGGAAACTTCCAGCCT
F. oxysporum NRRL22902             GGTCCAGGGTAGGTTCGCCAAATCCGTCAATCCGGCTTGAATC-----------GAAGGACAGGTCTAGGGTAGGCCAGAGTCGGGTCTAGGGTAGGCAACCCTCACCCT
F. subglutinans MRC8553            CACCCACGACCCGATCACCTCGTCCGTCGATTTGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. subglutinans MRC8554            CACCCACGACCCGATCACCTCGTCCGTCGATTTGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. subglutinans MRC6512            CACCCACGACCCGATCACCTCGTCCGTCGATTTGTCTTTATCT-----------GTGGGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. subglutinans MRC2802            CACCCCCGACCCGATCACCTCGTCCGTCGATTCGCCTTGAGAT-----------GTGAGACAGGTCTAGGGTAGGCCAAAGTCAGGTCTAGGGTAGGCAACTTCCAACCT
F. proliferatum CMW 12864          CACCCACGGTCGAATCACCTCGCCCGTCGATTCGCCTTGAGGT-----------GAGGGACAGGTCTAGGGTAGGCGAAAGTCGGGTCTAGGGTAGGAAACTTCCAGCCT
F. proliferatum MRC 2301           CACCCACGGTCGAATCACCTCGCCCGTCGATTCGCCTTGAGGT-----------GAGGGACAGGTCTAGGGTAGGCGAAAGTCGGGTCTAGGGTAGGAAACTTCCAGCCT
F. proliferatum CMW 12867          CACCCACGGTCGAATCACCTCGCCCGTCGATTCGCCTTGAGGT-----------GAGGGACAGGTCTAGGGTAGGCGAAAGTCGGGTCTAGGGTAGGAAACTTCCAGCCT
F. proliferatum MRC 8550           CACCCACGGTCGAATCACCTCGCCCGTCGATTCGCCTTGAGGT-----------GAGGGACAGGTCTAGGGTAGGCGAAAGTCGGGTCTAGGGTAGGAAACTTCCAGCCT
F. proliferatum MRC 8549           CACCCACGGTCGAATCACCTCGCCCGTCGATTCGCCTTGAGGT-----------GAGGGACAGGTCTAGGGTAGGCGAAAGTCGGGTCTAGGGTAGGAAACTTCCAGCCT
F. oxysporum CAV105                GGTCCAGGGTAGGTTCTCCAAATCCGTCAATCCGGCTTGAATC-----------GAAGGACAGGTCTAGGGTAGGCCAGAGTCGGGTCTAGGGTAGGCAGCTCTCACCCT
F. oxysporum CAV617                GGTCCAGGGTAGGTTCTCCAAATCCGTCAATCCGGCTTGAATC-----------GAAGGACAGGTCTAGGGTAGGCCAGAGTCGGGTCTAGGGTAGGCAGCTCTCACCCT
F. oxysporum CAV794                GGTCCAGGGTAGGTTCTCCAAATCCGTCAATCCGGCTTGAATC-----------GAAGGACAGGTCTAGGGTAGGCCAGAGTCGGGTCTAGGGTAGGCAGCTCTCACCCT
F. oxysporum CAV602                GGTCCAGGGTAGGTTCGCCAAATCCGTCAATCCGGCTTGAATC-----------GAAGGACAGGTTTAGGGTAGGCCAGAGTCGGGTTTAGGGTAGGCAACCCTCACCCT
F. oxysporum CAV929                GGTCCAGGGTAGGTTCGCCAAATCCGTCAATCCGGCTTGAATC-----------GAAGGACAGGTTTAGGGTAGGCCAGAGTCGGGTTTAGGGTAGGCAACCCTCACCCT
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                                    1770      1780      1790      1800      1810      1820      1830      1840      1850      1860      1870
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F. circinatum NRRL25331       CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum CAL2511         CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum FL2483          CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum FL2497          CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum MEX4900         CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum FL2496          CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum SA0041          CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum MEX2248         CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCCCCCCCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum SA0010          CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum FL2472          CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum SA1834          CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum MEX2265         CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. circinatum SP5498          CAGAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAATCGGTA
F. subglutinans NRRL22016     CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGGTGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. begoniae NRRL25300         CAAAGCTGCCTACCCGGGAGCCAATTTCAACCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAGCTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp. NRRL25346        CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp. NRRL25204        CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACTACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp. NRRL26756        CAAAGCTGCCTACCCGGGAGCCAATTTCGATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCAATGAACTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp. NRRL26757        CAAAGCTGCCTACCCGGGAGCCAATTTCGATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCAATGAACTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp. NRRL25623        CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp. NRRL25195        CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCCCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. succisae NRRL13613         CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGTACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTTGGTA
F. anthophilum NRRL13602      CAAAGCTGCCTACCCGGGAGTCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCACTGAACTCGCCTTGGTCGAAATAGTCGGTG
Fusarium sp. NRRL29123        CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGGTGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. bulbicola NRRL13618        CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGGTGCGATCACCCCCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp. NRRL25807        CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGGTGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
Fusarium sp.  NRRL25622       CGAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCGCGCCTCCCACAGACCTCGCACGAGGGTGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. bacterioides NRRL20476     CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGAGCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. pseudoanthophilum NRRL2520 CAAAGCTGCCTACCCGGTAGTCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCACGAAGATGGGACCACCTCCATCGCATTCGCCTTGGTCGAAATAGTCGGTA
F. verticillioides NRRL22172  CAAAGCTGCCTACCCGGTAGTCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCACGAAGATGAGACCACCTCCATCGCATTCGCCTTGGTCGAAATAGTCGGTA
F. thapsinum NRRL22045        CAAAGCTGCCTACCCGGTAGTCAGCTCCAATCGCCTCTCACGGCCGCCACGGACCTCGCACGAAGACGGGACCACCTCCATCGCATTCGCCGTGGTCGAAATAGTCGGTA
F. concentricum NRRL25303     CGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCACGAAGACGGGACCACCTCCATCGGATTTGCCTTGGCTGAAATAGTCGGTA
F. fractiflexum NRRL28852     CGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCGCAGACCTCGCACGAAGACGGGACCACCTTCATCGGATTCGCCTTGGTCGAAATAGTCGGTA
F. fujikuroi NRRL13566        CGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCACGAAGACGGGACCACCTCCATCGGATTCGCCTTGGTCGAAATGGTCGGTA
F. globosum NRRL26131         CGAAGCTGCCTACCCGGTAGCCAACCTCAATCGCCTCTCACGGCCGCCACGGCCCTCGCACGAAGACGGGACCACCTCCATCGGATTCGCCTTGGTCGAAATAGTCGGTA
F. proliferatum NRRL22944     CGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCAGGAAGACGGGACCACCTCCATCGGATTTGCCTTGGTCGAAATAGTCGGTA
F. oxysporum NRRL22902        CGAAGTGGTCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCATGACGACGGGACCACCACCATCGGATTCGCCTTGGTCGAAATAGCTGGTA
F. subglutinans MRC8553       CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGGTGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. subglutinans MRC8554       CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGGTGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. subglutinans MRC6512       CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGGTGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. subglutinans MRC2802       CAAAGCTGCCTACCCGGGAGCCAATTTCAATCGCCTCTCACGCCTCCCACAGACCTCGCACGAGGATGCGACCACCACCATTGAACTCGCCTTGGTCGAAATAGTCGGTA
F. proliferatum CMW 12864     TGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCAGGAAGACGGGACCACCTCCATCGGATTCGCCTTGGTCGAAATAGTCGGTA
F. proliferatum MRC 2301      CGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCAGGAAGACGGGACCACCTCCATCGGATTCGCCTTGGTCGAAATAGTCGGTA
F. proliferatum CMW 12867     TGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCAGGAAGACGGGACCACCTCCATCGGATTCGCCTTGGTCGAAATAGTCGGTA
F. proliferatum MRC 8550      TGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCAGGAAGACGGGACCACCTCCATCGGATTCGCCTTGGTCGAAATAGTCGGTA
F. proliferatum MRC 8549      TGAAGCTGCCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCAGGAAGACGGGACCACCTCCATCGGATTCGCCTTGGTCGAAATAGTCGGTA
F. oxysporum CAV105          CGAAGTGGTCTACCCGGTAGTCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCATGACGACGGGACCACCACCATCGGATTTGCCTTGGTCGAAATAGTCGGTA
F. oxysporum CAV617          CGAAGTGGTCTACCCGGTAGTCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCATGACGACGGGACCACCACCATCGGATTTGCCTTGGTCGAAATAGTCGGTA
F. oxysporum CAV794          CGAAGTGGTCTACCCGGTAGTCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCATGACGACGGGACCACCACCATCGGATTTGCCTTGGTCGAAATAGTTGGTA
F. oxysporum CAV602          CGAAGTGGTCTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCACGGACCTCGCATGACGACGGGACTACCACCATTGGATTCGCCTTGGTCGAAATAGCTGGTA
F. oxysporum CAV929          CGAAGTGGTTTACCCGGTAGCCAACTTCAATCGCCTCTCACGGCCGCCCCGGACCTCGAAAGACGACGGGACTACCCCCATCGGATTCGCCTTGGTCGAAATAGCTGGTA
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                                                 1880      1890      1900      1910      1920      1930      1940      1950      1960      1970      1980
                                             ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331                      TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum CAL2511                        TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum FL2483                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum FL2497                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum MEX4900                        TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum FL2496                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum SA0041                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum MEX2248                        TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum SA0010                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum FL2472                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum SA1834                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum MEX2265                        TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. circinatum SP5498                         TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. subglutinans NRRL22016                    TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. begoniae NRRL25300                        TACGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
Fusarium sp. NRRL25346                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCACATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
Fusarium sp. NRRL25204                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATGAAAAGTGGCCC
Fusarium sp. NRRL26756                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATCAAAAGTGGCCC
Fusarium sp. NRRL26757                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATCAAAAGTGGCCC
Fusarium sp. NRRL25623                       TATGCACTTTTGAAGAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
Fusarium sp. NRRL25195                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. succisae NRRL13613                        TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTACCATATAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. anthophilum NRRL13602                     TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAACAAAAAGTGGCCC
Fusarium sp. NRRL29123                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. bulbicola NRRL13618                       TATGCACTTTTGGAAAGAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
Fusarium sp. NRRL25807                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
Fusarium sp.  NRRL25622                      TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. bacterioides NRRL20476                    TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTCGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. pseudoanthophilum NRRL2520                TACGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. verticillioides NRRL22172                 TACGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. thapsinum NRRL22045                       TACGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTGCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. concentricum NRRL25303                    TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGTCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. fractiflexum NRRL28852                    TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAACTTTGCGGAAAATAAAAAGTGGCCC
F. fujikuroi NRRL13566                       TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. globosum NRRL26131                        TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCTC
F. proliferatum NRRL22944                    TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. oxysporum NRRL22902                       TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. subglutinans MRC8553                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. subglutinans MRC8554                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. subglutinans MRC6512                       TATGCACTTTTGAAAAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. subglutinans MRC2802                       TATGCACTTTTGAAGAAAAGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. proliferatum CMW 12864                    TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. proliferatum MRC 2301                     TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. proliferatum CMW 12867                    TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTCGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. proliferatum MRC 8550                     TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTCGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. proliferatum MRC 8549                     TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTCGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. oxysporum CAV105                          TATGCACTTTTGAAAAAATGCGTGCAAAATGGCTTTGTGGTTTGGTGGTCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. oxysporum CAV617                          TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGTCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. oxysporum CAV794                          TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGTCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. oxysporum CAV602                          TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
F. oxysporum CAV929                          TATGCACTTTTGAAAAAATGCGTGCAAAATGGTTTTGTGGTTTGGTGGCCGTGAGTCGATTTTTTTGTTTTCCCATACAAATGAATTTTGCGGAAAATAAAAAGTGGCCC
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                                    1990      2000      2010      2020      2030      2040      2050      2060      2070      2080      2090
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F. circinatum NRRL25331        ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum CAL2511          ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum FL2483           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum FL2497           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum MEX4900          ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum FL2496           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum SA0041           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum MEX2248          ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum SA0010           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum FL2472           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum SA1834           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum MEX2265          ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. circinatum SP5498           ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. subglutinans NRRL22016      ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. begoniae NRRL25300          ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
Fusarium sp. NRRL25346         ACGAGGCAGTTCCGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
Fusarium sp. NRRL25204         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
Fusarium sp. NRRL26756         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
Fusarium sp. NRRL26757         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
Fusarium sp. NRRL25623         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
Fusarium sp. NRRL25195         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. succisae NRRL13613          ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCAACCTC
F. anthophilum NRRL13602       ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGGAAACCGGACAAGCAACCTC
Fusarium sp. NRRL29123         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. bulbicola NRRL13618         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
Fusarium sp. NRRL25807         ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
Fusarium sp.  NRRL25622        ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. bacterioides NRRL20476      ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCCCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. pseudoanthophilum NRRL2520  ACGAGGCGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. verticillioides NRRL22172   ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. thapsinum NRRL22045         ACGAGACGGTTCTGGCGTGCGGTCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. concentricum NRRL25303      ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. fractiflexum NRRL28852      ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. fujikuroi NRRL13566         ACGAGGCAGTTCTGGCGTGCGGTCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. globosum NRRL26131          ACGAGACGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. proliferatum NRRL22944      ACGAGACGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. oxysporum NRRL22902         ACGAGGCAGTCCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGTGAGGACAAACCGGGCGAGCAACCTC
F. subglutinans MRC8553        ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. subglutinans MRC8554        ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGGGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. subglutinans MRC6512        ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. subglutinans MRC2802        ACGAGGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACAAGCGACCTC
F. proliferatum CMW 12864      ACGAGACGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGCGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. proliferatum MRC 2301       ACGAGACGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGG-CCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. proliferatum CMW 12867      ACGAGACGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. proliferatum MRC 8550       ACGAGACGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. proliferatum MRC 8549       ACGAGACGGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGGAAAACCGGACGAGCAACCTC
F. oxysporum CAV105            ACGAAGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGCGAGGACAAACCGGGCGAGCAACCTC
F. oxysporum CAV617            ACGAAGCAGCTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGTGAGGACAAACCGGGCGAGCAACCTC
F. oxysporum CAV794            ACGAAGCAGTTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGTGAGGACAAACCGGGCGAGCAACCTC
F. oxysporum CAV602            ACGAGGCAGCTCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGAGGCAAATCCGGCCGAGCCTGAAAGGGTGAGGACAAACCGGGCGAGCAACCTC
F. oxysporum CAV929            ACGAGGCAGTCCTGGCGTGCGGCCCACTAAAACGGTCTCGGAGGGTATATGAGAAGGGAGCAAATCCGGCCGAGCCTGAAAGGGTGAGGACAAACCGGGCGAGCAACCTC
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                                       2100      2110      2120      2130      2140      2150      2160      2170      2180      2190      2200
                               ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331        T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum CAL2511          T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum FL2483           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum FL2497           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum MEX4900          T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum FL2496           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum SA0041           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum MEX2248          T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum SA0010           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum FL2472           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum SA1834           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum MEX2265          T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGCTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. circinatum SP5498           T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. subglutinans NRRL22016      TCCGTATCTGATCTTGAAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. begoniae NRRL25300          T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
Fusarium sp. NRRL25346         T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
Fusarium sp. NRRL25204         T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
Fusarium sp. NRRL26756         T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCCCCACGAAACTGCT
Fusarium sp. NRRL26757         T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCCCCACGAAACTGCT
Fusarium sp. NRRL25623         TCCGTATCTGATCTTGAAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
Fusarium sp. NRRL25195         TCCGTATCTGATCTTGAAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. succisae NRRL13613          T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. anthophilum NRRL13602       T-CGTACCTGATCTTAAAGACTTCCATTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
Fusarium sp. NRRL29123         TCCGTATCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. bulbicola NRRL13618         TCCGTATCTGATCTTGAAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
Fusarium sp. NRRL25807         TCCGTATCTGATCTTGAAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
Fusarium sp.  NRRL25622        TCCGTATCTGATCTTGAAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. bacterioides NRRL20476      TCCGTATCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCT
F. pseudoanthophilum NRRL2520  T-CGTACCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. verticillioides NRRL22172   T-CGTACCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. thapsinum NRRL22045         T-CGTACCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. concentricum NRRL25303      T-CGTACCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. fractiflexum NRRL28852      T-CGTACCTGATCTTGAAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. fujikuroi NRRL13566         T-CGTACCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. globosum NRRL26131          T-CGTACCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. proliferatum NRRL22944      T-CGTACCTGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGGCTCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. oxysporum NRRL22902         TCAGTATCAGATCTTGCAGACTTCCACTGCGTGTCCCTCTGTACAGCTTTGCAGG-TCCGGCCTCGGCAGCGGGGGGTTCATAGTGGTCGTCGACCTCCACGAAACTGCA
F. subglutinans MRC8553        TCCGT-----------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554        TCC--------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512        TCCG-------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802        TCCG-------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864      TCGT-------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301       TC---------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867      TC---------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550       TC---------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549       TC---------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105            TCA--------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617            TCAGTATCAG-------------------------------------------------------------------------------------------------------
F. oxysporum CAV794            TCAGTA-----------------------------------------------------------------------------------------------------------
F. oxysporum CAV602            TCAGTATCAG-------------------------------------------------------------------------------------------------------
F. oxysporum CAV929            TCAG-------------------------------------------------------------------------------------------------------------
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                              2210      2220      2230      2240      2250      2260      2270      2280      2290      2300      2310
                          ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331   CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum CAL2511     CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum FL2483      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum FL2497      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum MEX4900     CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum FL2496      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum SA0041      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum MEX2248     CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum SA0010      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum FL2472      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum SA1834      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum MEX2265     CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. circinatum SP5498      CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. subglutinans NRRL22016 CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. begoniae NRRL25300     CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL25346    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL25204    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL26756    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL26757    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL25623    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL25195    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. succisae NRRL13613     CGCCCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. anthophilum NRRL13602  CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL29123    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. bulbicola NRRL13618    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp. NRRL25807    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
Fusarium sp.  NRRL25622   CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. bacterioides NRRL20476 CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. pseudoanthophilum NRRL2520 CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. verticillioides NRRL22172 CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. thapsinum NRRL22045    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. concentricum NRRL25303 CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. fractiflexum NRRL28852 CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. fujikuroi NRRL13566    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. globosum NRRL26131     CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. proliferatum NRRL22944 CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTTTACGCAGTCCGGGCTTGCCTGGACCGCCAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. oxysporum NRRL22902    CGCTCCGGCGTGACAGCGTACTGGGGATGCCTGTGTAGATGCAGTCCGGGCTTGCCTGGACCGCTAGCAGATGGGCTCTGTGGATGACTGGCCGCTGGCTAGACCTGAAA
F. subglutinans MRC8553   --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554   --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512   --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802   --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864 --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301  --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867 --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550  --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549  --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105       --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617       --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794       --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602       --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929       --------------------------------------------------------------------------------------------------------------
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                                     2320      2330      2340      2350      2360      2370      2380      2390      2400      2410      2420
                               ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331        CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum CAL2511          CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum FL2483           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum FL2497           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum MEX4900          CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum FL2496           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum SA0041           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum MEX2248          CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum SA0010           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum FL2472           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum SA1834           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum MEX2265          CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. circinatum SP5498           CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACGCCTCCCACAGCGGGTTCGGTG
F. subglutinans NRRL22016      CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCCAAGCCACACCTCCCACAGCGGGTTCGGTG
F. begoniae NRRL25300          CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCCAAGCCACACCTCCCACAGCGGGTTCGGTG
Fusarium sp. NRRL25346         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
Fusarium sp. NRRL25204         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
Fusarium sp. NRRL26756         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
Fusarium sp. NRRL26757         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
Fusarium sp. NRRL25623         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGCAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
Fusarium sp. NRRL25195         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. succisae NRRL13613          CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. anthophilum NRRL13602       CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
Fusarium sp. NRRL29123         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCCAAGCCACACCTCCCACAGCGGGCTCGGTG
F. bulbicola NRRL13618         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGCTCGGTG
Fusarium sp. NRRL25807         CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGCTCGGTG
Fusarium sp.  NRRL25622        CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCCAAGCCACACCTCCCACAGCGGGTTCGGTG
F. bacterioides NRRL20476      CCTGAGCAACGGGAGGTAACCTCTCGCCGTGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCCCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. pseudoanthophilum NRRL2520  CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCCAAGCCACACCTCCCACAGCGGGCTCGGTG
F. verticillioides NRRL22172   CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. thapsinum NRRL22045         CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. concentricum NRRL25303      CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. fractiflexum NRRL28852      CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCCAAGCCACACCTCCCACAGCGGGTTCGGTG
F. fujikuroi NRRL13566         CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. globosum NRRL26131          CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. proliferatum NRRL22944      CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCACAGCGGGTTCGGTG
F. oxysporum NRRL22902         CCTGAGCAACGGGAGGTAACCTCTCGCCGCGGACACCGGAATGGTAGAAGCGGCGTGCTGCGTCCTCCTCTTGGGGCCCCTAAGCCACACCTCCCATAGCGGGTTCGGTG
F. subglutinans MRC8553        --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554        --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512        --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802        --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864      --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301       --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867      --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550       --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549       --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105            --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617            --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794            --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602            --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929            --------------------------------------------------------------------------------------------------------------
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                                   2430      2440      2450      2460      2470      2480      2490      2500      2510      2520      2530
                              ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
F. circinatum NRRL25331       CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum CAL2511         CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum FL2483          CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum FL2497          CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum MEX4900         CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum FL2496          CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum SA0041          CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum MEX2248         CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum SA0010          CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTC-CCACCCA
F. circinatum FL2472          CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum SA1834          CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum MEX2265         CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. circinatum SP5498          CGGCGGACGGACGCCCTGAGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGCTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. subglutinans NRRL22016     CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCTTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. begoniae NRRL25300         CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL25346        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL25204        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL26756        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL26757        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL25623        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL25195        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. succisae NRRL13613         CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. anthophilum NRRL13602      CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL29123        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. bulbicola NRRL13618        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp. NRRL25807        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
Fusarium sp.  NRRL25622       CGGTGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. bacterioides NRRL20476     CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. pseudoanthophilum NRRL2520 CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. verticillioides NRRL22172  CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. thapsinum NRRL22045        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. concentricum NRRL25303     CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. fractiflexum NRRL28852     CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. fujikuroi NRRL13566        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. globosum NRRL26131         CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. proliferatum NRRL22944     CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. oxysporum NRRL22902        CGGCGGACGGACGCCCTGGGGAATTTAGAGGGGGAAAGCGGATTGCCCTAGCGGTGTTGTTGGCCCTGCCGACCTCACTGCGAAAGGCGCGACTTCACCGTCGCCACCCA
F. subglutinans MRC8553       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC8554       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC6512       --------------------------------------------------------------------------------------------------------------
F. subglutinans MRC2802       --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12864     --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 2301      --------------------------------------------------------------------------------------------------------------
F. proliferatum CMW 12867     --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8550      --------------------------------------------------------------------------------------------------------------
F. proliferatum MRC 8549      --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV105           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV617           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV794           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV602           --------------------------------------------------------------------------------------------------------------
F. oxysporum CAV929           --------------------------------------------------------------------------------------------------------------
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                                        2540      2550
                                    ....|....|....|....|....|.
F. circinatum NRRL25331             GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum CAL2511               GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum FL2483                GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum FL2497                GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum MEX4900               GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum FL2496                GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum SA0041                GTAACTTGTCTCTCCGGCGCCTCACN
F. circinatum MEX2248               GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum SA0010                GTAACTTGTCTCTCCGGCGCCTCACN
F. circinatum FL2472                GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum SA1834                GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum MEX2265               GTAACTTGTCTCTCCGGCGCCTCACG
F. circinatum SP5498                GTAACTTGTCTCTCCGGCGCCTCCGG
F. subglutinans NRRL22016           GTAACTTGTCTCTCCGGCGCCTCACG
F. begoniae NRRL25300               GTAACTTGTCTCTCCGGCGCCTCACG
Fusarium sp. NRRL25346              GTAACTTGTCTCTCCGGCGCCTCACG
Fusarium sp. NRRL25204              GTAACTTGTCTCTCCGGCGCCTCACG
Fusarium sp. NRRL26756              GTAACTTGTCTCTCCGGCGCTTCACG
Fusarium sp. NRRL26757              GTAACTTGTCTCTCCGGCGCTTCACG
Fusarium sp. NRRL25623              GTAACTTGTCTCTCCGGCGCTTCACG
Fusarium sp. NRRL25195              GTAACTTGTCTCTCCGGCGCTTCACG
F. succisae NRRL13613               GTAACTTGTCTCTCCGGCGCCTCACG
F. anthophilum NRRL13602            GTAACTTGTCTCTCCGGCGCCTCACG
Fusarium sp. NRRL29123              GTAACTTGTCTCTCCGGCGCCTCACG
F. bulbicola NRRL13618              GTAACTTGTCTCTCCGGCGCTTCACG
Fusarium sp. NRRL25807              GTAACTTGTCTCTCCGGCGCTTCACG
Fusarium sp.  NRRL25622             GTAACTTGTCTCTCCGGCGCCTCACG
F. bacterioides NRRL20476           GTAATTTGTCTCTCCGGCGCCTCACG
F. pseudoanthophilum NRRL2520       GTAACTTGTCTCTCCGGCGCCTCACG
F. verticillioides NRRL22172        GTAACTTGTCTCTCCGGCGCCTCACG
F. thapsinum NRRL22045              GTAACTTGTCTCTCCGGCGCCTCACG
F. concentricum NRRL25303           GTAACTTGTCTCTCCGGCGCTTCACG
F. fractiflexum NRRL28852           GTAACTTGTCTCTCCGGCGCTTCACG
F. fujikuroi NRRL13566              GTAACTTGTCTCTCCGGCGCTTCACG
F. globosum NRRL26131               GTAACTTGTCTCTCCGGCGCTTCACG
F. proliferatum NRRL22944           GTAACTTGTCTCTCCGGCGCCTCACG
F. oxysporum NRRL22902              GTAACTTGTCTCTCCGGCGCTTCACG
F. subglutinans MRC8553             --------------------------
F. subglutinans MRC8554             --------------------------
F. subglutinans MRC6512             --------------------------
F. subglutinans MRC2802             --------------------------
F. proliferatum CMW 12864           --------------------------
F. proliferatum MRC 2301            --------------------------
F. proliferatum CMW 12867           --------------------------
F. proliferatum MRC 8550            --------------------------
F. proliferatum MRC 8549            --------------------------
F. oxysporum CAV105                 --------------------------
F. oxysporum CAV617                 --------------------------
F. oxysporum CAV794                 --------------------------
F. oxysporum CAV602                 --------------------------
F. oxysporum CAV929                 --------------------------
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