

A microscopic image showing a dense population of dark, spherical spores with long, thin, radiating filaments. Some spores are clustered together, and there are some yellowish, irregular structures scattered throughout the field of view. The background is a light brown, granular texture.

CHAPTER 5

A phylogenetic study of *Ceratocystis moniliformis* and description
of *Ceratocystis tribiliformis* prov. nom.

ABSTRACT

Ceratocystis moniliformis is a colonist of fresh wounds on trees, mainly in the tropics. The fungus is not known to be a pathogen and it has thus not been widely studied. *Ceratocystis moniliformis* has been found on many taxonomically different plants and in many different climatic zones. It is thought to represent a complex of morphologically similar but different species, of which some have recently been described. The aim of this study was to consider the phylogenetic relationships of isolates of *C. moniliformis* from various hosts and origins, based on DNA sequence comparisons of three gene regions. Four recently described species, closely related to *C. moniliformis*, were included in the study and confirmed to be phylogenetically distinct. Results showed that the isolates of *C. moniliformis* used in this study represent a monophyletic group. A collection of isolates initially identified as *C. moniliformis*, from *Quercus* in Sumatra represented a distinct clade. These isolates are also morphologically distinct from *C. moniliformis* and this fungus is described here as *Ceratocystis tribilliformis* prov. nom.

INTRODUCTION

Ceratocystis moniliformis Hedgcock is a cosmopolitan fungus, which has been reported from many hosts and continents (Davidson 1935, Bakshi 1951, Hunt 1956, Upadhyay 1981) (Table 1). The fungus was first collected from gumwood (*Liquidambar styraciflua* L.) in Texas (Von Schrenk 1903) and was initially described as *Ceratostomella moniliformis* (Hedgcock 1906). The species was transferred to *Ceratocystis* in 1952 (Moreau 1952).

Ceratocystis moniliformis is one of six species belonging to the genus that has hat-shaped ascospores. It can, however, easily be distinguished from the other *Ceratocystis* spp. This is generally based on the presence of well-developed conical spines that cover the ascomatal bases of *C. moniliformis* isolates (Hedgcock 1906, Luc 1952, Hunt 1956, Upadhyay 1981). Another distinguishing characteristic are the disc-formed bases of the ascomatal necks (Bakshi 1951, Hunt 1956). Two types of conidia, one cylindrical in shape and the other more barrel-shaped, have been reported for the *Thielaviopsis* anamorph of *C. moniliformis* (Davidson 1935, Bakshi 1951, Paulin-Mahady, Harrington & McNew 2002). *Ceratocystis moniliformis* is one of the few *Ceratocystis* spp. known not to produce chlamydospores (Davidson 1935, Paulin-Mahady *et al.* 2002).

Descriptions for *C. moniliformis* have tended to be somewhat disparate. For example, the conical spines on ascomatal bases were not noted by some authors (Kitajima 1936, Luc 1952, Roldan 1962) who rather referred to hyphal ornamentation. The ascomatal bases have also been described variably as globose (Hedgcock 1906), elongate to pear-shaped (Davidson 1935) and spherical or elongated (Luc 1952). Dimensions for neck length and ascomatal base widths have also varied (Hedgcock 1906, Kitajima 1936, Bakshi 1951, Hunt 1956, Upadhyay 1981) (Table 2). Likewise, there has been little agreement regarding the morphology of the conidiophores in various descriptions (Davidson 1935, Kitajima 1936, Bakshi 1951, Hunt 1956, Upadhyay 1981) (Table 3).

Ceratocystis moniliformis commonly infects wounds on woody plants and especially trees (Grylls & Seifert 1993, Kile 1993). It is not considered to be a pathogen, causing only sap stain. There is also no evidence of *C. moniliformis* imparting structural changes to infected wood, but discolouration does lead to reduction of timber value (Davidson 1935).

The very wide host range and geographic distribution of *C. moniliformis* has led us to question whether this fungus might represent a species complex. This would be similar to the view that is emerging for the important tree pathogen, *C. fimbriata* Ell. & Halst. (Barnes 2002, Baker *et al.* 2003). The recent description of *C. moniliformopsis* Yuan & Mohammed (Yuan & Mohammed 2002), a species morphologically very similar to *C. moniliformis*, provided the first support for the view that various species might have been aggregated with *C. moniliformis*. Recent phylogenetic studies have thus led to the discovery of two additional new species, *C. bhutanensis* *prov. nom.* Van Wyk, Krisits & Wingfield (Chapter 2) and *C. omanensis* *prov. nom.* Al-Alsubhi, Deadman & Wingfield (Al-Alsubhi *et al.* 2003) that are morphologically very similar to *C. moniliformis*.

The aim of this study was to compare a collection of *C. moniliformis sensu lato* isolates based on multiple gene sequences. Recently described species such as *C. moniliformopsis*, *C. bhutanensis* and *C. omanensis* were also included to provide perspective.

MATERIALS & METHODS

Isolates

Isolates collected for this study were identified as *C. moniliformis* based on morphological characteristics such as the presence of spines on the ascomatal bases. Isolates were collected over a relatively long period (7 years) from various tree species in South Africa, Bhutan, Ecuador, Costa Rica and Indonesia (Table 4). Closely related species, *C. moniliformopsis*, *C. bhutanensis* *prov. nom.* and *C. omanensis* *prov. nom.*, originally identified as *C. moniliformis* due to their morphological similarities, were also included (Table 4). All isolates used in this study are maintained in the culture collection (CMW) of the Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa. Representative isolates have also been deposited with the Centraalbureau voor Schimmelcultures (CBS), Utrecht, The Netherlands.

DNA extraction

Cultures for DNA extraction were grown on 2 % Malt Extract Agar (MEA) (20 % w/v) (Biolab, Midrand, South Africa) at 25 °C for two weeks. Masses of fungal mycelium and ascomata were scraped directly from the actively growing cultures and transferred to Eppendorf tubes and lyophilised for two days. The lyophilised mycelium was placed in liquid nitrogen, ground to a fine powder using a glass rod, and DNA was extracted using the method described by Barnes *et al.* (2001).

PCR amplification

Three gene regions were amplified using the polymerase chain reaction (PCR). The two Internal Transcribed Spacer regions (ITS1 and ITS2) and the 5.8S gene of the ribosomal DNA (rDNA) operon were amplified using primers ITS1 and ITS4 (White *et al.* 1990). The β -tubulin gene was partially amplified using primers β t1a and β t1b (Glass & Donaldson 1995) and the EF1- α gene of the rDNA operon was amplified using primers EF1-728F and EF1-986R (Carbone & Kohn 1999).

PCR reaction mixtures consisted of 200 nM of the forward and reverse primers, 200 μ M of each dNTP, Expand High Fidelity PCR System enzyme mix (1.75 U) (Roche Diagnostics, Mannheim, Germany), 1 x Expand HF Buffer containing 1.5 mM MgCl₂ (supplied with the enzyme) and 2-10 ng DNA. Reaction volumes were adjusted to 25 μ L with sterile water. The PCR programme was set at 96 °C for 2 min for DNA denaturation, followed by 10 cycles at 94 °C for 20 s and 55 °C for 40 s for annealing and 72 °C for 45 s for elongation. A further 30 cycles at 94 °C for 20 s, 55 °C for 40 s with a 5 s extension after each cycle were included. A final step of 10 min at 72 °C completed the programme. Amplification of the respective genes was confirmed under UV illumination using 2 % agarose (Roche diagnostics, Mannheim, Germany) gel electrophoresis in the presence of ethidium bromide. After amplification, amplicons were purified using Sephadex G-50 columns (1 g in 15 ml H₂O, SIGMA, Steinheim, Germany).

Sequencing and analysis

PCR amplicons were sequenced in both directions using the ABI PRISM™ Big DYE Terminator Cycle Sequencing Ready Reaction Kit (Applied BioSystems, Foster City, California). The same primers as those used in the PCR reactions were used for sequencing.

Sequencing reactions were run on an ABI PRISM™ 3100 Autosequencer (Applied BioSystems, Foster City, California, U.S.A) and sequences were analysed using Sequence Navigator version 1.0.1 (Applied BioSystems, Foster City, California).

Sequences were aligned manually and analysed using PAUP version 4.0b10* [Phylogenetic Analysis Using Parsimony (and other methods)] (Swofford 2002). A partition homogeneity test (Swofford 2002) was used to determine whether the sequence data sets for the three different genome regions could be combined for the analysis. Gaps were treated as “newstate” and trees were obtained via stepwise addition of 1000 replicates with the Mulpar option effective. The heuristic search option based on parsimony with tree bisection reconnection was used to obtain the phylogram. Confidence intervals using 1000 bootstrap replicates were calculated. *Ceratocystis virescens* (Davidson) Moreau was used as a monophyletic sister out-group with respect to the in-group. All sequences derived from this study have been deposited in GenBank (Table 4).

The Markov Chain Monte Carlo (MCMC) method (Larget & Simon 1999), with a Bayesian framework was used to estimate the posterior probability of nodes in the phylogenetic tree. One hundred thousand random trees were generated using the MCMC procedure, sampling every 100th tree and saving every 10th tree. To avoid including trees sampled before convergence of the Markov chain, the first 4700 trees were discarded. For the combined dataset of the three gene sequences, gamma rate heterogeneity was set, and no codon specific sites were included for the ITS gene. For β -tubulin and EF1- α sequences, codon specific sites were specified with a site-specific substitution rate and the site partition was treated as a by-codon.

Cultural Characteristics

To supplement DNA sequence data, isolates were compared based on morphology and growth in culture. For growth comparisons, three isolates from each of the different countries were chosen (Table 4). Three representative isolates of the closely related species, *C. moniliformopsis*, *C. bhutanensis* prov. nom. and *C. omanensis* prov. nom. were also included.

Prior to commencing the growth tests, the fungi were grown on 2 % MEA. After a two-week incubation period at 25 °C, mycelial plugs were taken from the margins of the actively

growing cultures using a 5 mm diameter cork borer, and these were transferred to the centres of 90 mm Petri dishes containing 2 % MEA. Five plates of each isolate were incubated at 4 °C, 10 °C, 15 °C, 20 °C, 25 °C, 30 °C and 35 °C, respectively. Growth rates were assessed by taking two measurements of colony diameter at right angles to each other, every day for 3 days. Averages and standard deviations were computed in Microsoft Excel for all growth measurements. The entire experiment was repeated once. The colony colour of the isolates was determined using the colour tables of Rayner (1970) and colony textures were noted.

Morphology

Isolates were further compared by studying fungal structures using a Zeiss Model light microscope. These comparisons showed that there was a group of isolates that were distinctly different to other isolates of *C. moniliformis*. These morphologically different cultures were subjected to further detailed studies.

Morphological characteristics of the isolates residing in a unique clade, related to *C. moniliformis* (Fig. 3), were described from 10-day-old cultures on 2 % MEA. For microscopic examination, fungal structures were mounted in lactophenol on glass slides. Fifty measurements were taken for each taxonomically relevant structure of isolate CMW 13013, which was chosen to represent the fungus reflected by this unique clade. In addition, ten measurements were made of each of the relevant structures for three other isolates chosen from this unique group (Table 4). Ranges, averages, and standard deviations of all measurements were calculated in Microsoft Excel.

RESULTS

PCR amplification

Amplification of the ITS regions and the 5.8S gene of the rDNA operon resulted in fragments of ~500 base pairs (bp) in size. Amplification of the β -tubulin gene resulted in fragments of ~500 bp in size, while the amplification of the EF1- α gene resulted in fragments of ~300 bp in size. All three gene regions were successfully amplified for all isolates.

Sequencing and analyses

The partition homogeneity test showed that the sequence data sets for β -tubulin, ITS and EF 1- α could be combined ($P = 0.05$). The combined data set resulted in 1310 characters (Appendix), of which 349 characters were variable, 213 were parsimony-uninformative and 186 were parsimony informative. Analyses of the data set resulted in two most parsimonious trees, with a tree length of 632, a consistency index (CI) of 0.908, homoplasy index (HI) of 0.09, retention index (RI) of 0.894 and a rescaled consistency index (RC) of 0.812.

Five distinct clades, representing four different phylogenetic species were observed in the combined gene tree, each supported by a 100 % bootstrap value (Fig. 1). The *C. moniliformis* group was separated into two distinct clades. The one clade included only isolates from Sumatra, which were from *Quercus* trees, while the second clade represented all the other *C. moniliformis* isolates used in this study, originating from Bhutan, South Africa, Ecuador and Costa Rica. The posterior probability of the branch nodes of the combined tree, generated with the Bayesian inference programme, supported the bootstrap values (Fig. 1).

Cultural characteristics

There were distinct differences in growth and culture for the *C. moniliformis* isolates studied. The isolates from Sumatra grew rapidly, reaching a colony diameter of 90 mm in 5 days at 25 °C (Fig. 2). No growth was observed at 4 °C or at 35 °C. At 10 °C and at 30 °C, the growth was diminished. The growth for the other *C. moniliformis* isolates varied significantly (Fig. 2). At 4 °C and 35 °C there was no growth for any of the isolates. At 10 °C, 15 °C, 20 °C, 25 °C and 30 °C there were considerable differences between isolates (Fig. 2). Isolates of *C. moniliformopsis* grew slowly compared to *C. moniliformis*. They displayed optimal growth at 20 °C and did not grow at temperatures above this (Fig. 2). Isolates of *C. omanensis* *prov. nom.* grew faster than any other species at most of the temperatures, including 35 °C (Fig. 2). Optimum growth was observed between 25 °C to 30 °C (Fig. 2). Isolates of *C. bhutanensis* *prov. nom.* grew well at most temperatures and had optimum growth at 20 °C. This species displayed much better growth than any other species at temperatures below 20 °C (Fig. 2).

Ceratocystis moniliformopsis cultures had buff-yellow (19d) aerial mycelium with isabella colour (19"i) submerged mycelium, with older cultures having fawn (13"") aerial and

submerged mycelium, with few ascomata observed while *C. bhutanensis* prov. nom. culture's submerged mycelium was umber (15 m) with the well-developed aerial mycelium being ecru-drab (13''''d). *Ceratocystis omanensis* prov. nom. cultures were buff-yellow (19d) in colour with masses of ascomata. The *C. moniliformis* isolates could be separated into two broad groups that were consistent with those emerging from the phylogenetic comparisons. Isolates from Sumatra differed from others in having virtually no aerial mycelium and masses of ascomata covering the plates. The remaining *C. moniliformis* isolates had abundant buff-yellow (19d) (Rayner 1970) aerial mycelium with ascomata tending to occur below the mycelium, which is consistent with the description of this species (Hedgcock 1906, Upadhyay 1981).

Morphology

Phylogenetic analyses and differences in cultural characteristics for the Sumatran isolates prompted a more detailed morphological comparison between them and those thought to represent typical *C. moniliformis*. The ascomatal bases for the Sumatran isolates were black and obpyriform (Fig. 3a) and the ostiolar hyphae were divergent (Fig. 3b). The bases of the necks at the points of attachment resembled those of *C. moniliformis* (Fig. 3c). The ascomatal bases also resembled those of typical *C. moniliformis*, which were covered in short conical spines (Fig. 3d). Masses of hat-shaped ascospores were observed in both groups of isolates (Fig. 3e). The anamorph was typical of *Thielaviopsis*, with phialidic conidiogenous cells (Fig. 3f). Both smooth-walled hyphae and those having a granular appearance were observed (Fig. 3g) and both barrel-shaped (Fig. 3h) and cylindrical conidia were present (Fig. 3i).

TAXONOMY

DNA Sequence comparisons as well as growth characteristics in culture provided robust support for the view that the isolates thought to represent *C. moniliformis* from Sumatra included in this study, represent a new and previously undescribed species of *Ceratocystis*. The fungus is, therefore, described here as a new taxon:

Ceratocystis tribiliformis Van Wyk & Wingfield prov. nom.

(Fig. 3)

Etymology: Ascomata similar in shape to fruit of the plant *Tribulus terrestris*, known in the Afrikaans language as the "dubbeltjie".

Stat.conid.: *Thielaviopsis*

Coloniae colore albae. *Mycelium* rarum, praecipue in medio immersum. *Temperatura faustissima* 25 °C, supra 30 °C non crescit, minime crescit ad 4 °C et 30 °C. *Hyphae* laeves vel granulatae, in septis non constrictae, 2-4 µm latae. *Bases ascomatum* atrobrunneae vel nigrae, obpyriformes, spinis hyphibusque ornatae, spinis atrobrunneis vel nigris, (4-) 6-10 (-12) µm longis, bases (196-) 203-249 (-264) µm diametro. *Colla ascomatum* atrobrunnea vel nigra, (741-) 782-986 (-1047) µm longa, basi discoidea, (43-) 44-50 (-53) µm lata, apice (13-) 14-18 (-20) µm lata. *Hyphae ostiolaris* divergentes, hyalinae, (22-) 25-31 (-32) µm longae. *Asci* non visi. *Ascospores* lateraliter visae cucullatae, aseptatae, hyalinae, in vagina investitae, cum vagina 5-6 x 2-3 µm, sine illa 4-5 x 2-3 µm. Ascospores in massis bubalino-luteis mucilaginis in apicibus collorum ascomatum convenientes. *Anamorpha Thielaviopsis*: conidiophora singula in mycelio crescentia, apicem versus angustata, (21-) 22-40 (-46) µm longa, basi 3-4 µm, apice 1-3 µm lata. Evolutio *conidii* phialidici per parietes annulares faciendas, *conidia* biformia: conidia primaria hyalina, aseptata, cylindrica 7-9 x 2 µm, conidia secundaria hyalina, aseptata, doliiformia, 7-9 x 3-4 µm.

Typus: **Indonesia**: Sumatra, isolated from *Quercus* sp., 1996, M. J. Wingfield (PREM 57827 – holotypus, living culture: CMW 13013).

Colonies white in colour. *Mycelium* sparse, mostly submerged in medium. *Optimal temperature* for growth 25 °C, no growth above 30 °C, diminished growth at 4 °C and 30 °C. *Hyphae* smooth or granulated, not constricted at septa, 2-4 µm wide. *Ascomatal bases* dark brown to black, globose to obpyriform, ornamented with spines and hyphae, spines dark brown to black, (4-) 6-10 (-12) µm long, bases (196-) 203-249 (-264) µm in diameter. *Ascomatal necks* dark brown to black, (741-) 782-986 (-1047) µm long, (43-) 44-50 (-53) µm wide at the base, (13-) 14-18 (-20) µm wide at the apex, with a disc-like base. *Ostiolar hyphae* divergent, hyaline, (22-) 25-31 (-32) µm long. *Asci* not observed. *Ascospores* cucullate in side view, aseptate, hyaline, invested in sheath, 5-6 x 2-3 µm with sheath, 4-5 x 2-3 µm without sheath. Ascospores accumulating in buff-yellow (19d) mucilaginous masses on the apices of ascomatal necks. *Thielaviopsis anamorph*: conidiophores occurring singly on mycelium,

hyaline, swollen at the base, tapering towards the apex, (21-) 22-40 (-46) μm long, 3-4 μm wide at base, 1-3 μm wide at the apices. *Conidium development* through ring wall building, *conidia* of two types: primary conidia hyaline, aseptate, cylindrical 7-9 x 2 μm , secondary conidia hyaline, aseptate, barrel-shaped 7-9 x 3-4 μm .

Additional specimens examined: Indonesia: Sumatra, isolated from *Quercus* sp., 1996, M. J. Wingfield (culture CMW 13 011, PREM 57825); same collection data (culture CMW 13 012, PREM 57826); same collection data (culture CMW 13 015, PREM 57828).

DISCUSSION

In this study, we investigated the taxonomic status of a group of isolates reported to represent *C. moniliformis*. This was achieved using both morphological and DNA sequence data. Our results show that a set of isolates identified as *C. moniliformis sensu stricto* in fact represent two discrete phylogenetic lineages. One of the clades, consisting of isolates from a wide geographic and host range represent true *C. moniliformis sensu stricto*. The second group of isolates, from Sumatra, Indonesia, isolated from *Quercus* trees, clearly represent a separate and undescribed species. We have now described this species as *C. tribiliformis prov. nom.* We have also provided additional support for the separation of *C. bhutanensis prov. nom.*, *C. omanensis prov. nom.* and *C. moniliformopsis* into separate species, most closely related to *C. moniliformis*. We consider these species to form part of the larger *C. moniliformis sensu lato* complex, characterised by the formation of hat-shaped ascospores, a disk-shaped basal ascomatal neck and short conical spines on their ascomatal bases.

Ceratocystis tribiliformis prov. nom. is morphologically very similar to *C. moniliformis*. Small but distinct differences in the morphology of fruiting structures could be found to separate them. The ascomatal bases of *C. tribiliformis prov. nom.* are very characteristically obpyriform to globose while *C. moniliformis*, *C. omanensis prov. nom.*, *C. bhutanensis prov. nom.* and *C. moniliformopsis* all have distinctly globose bases. *Ceratocystis tribiliformis prov. nom.*, *C. omanensis prov. nom.* and *C. bhutanensis prov. nom.* have both smooth hyphae such as in *C. moniliformis* and *C. moniliformopsis*, and hyphae with granular surfaces. These fungi can also easily be distinguished from each other based on growth characteristics in culture. In

culture, *C. tribiliformis prov. nom.* has very little, if any, aerial mycelium, while all the other species in the *C. moniliformis sensu lato* complex produce prolific aerial mycelium (Hedgcock 1906, Davidson 1935, Yuan & Mohammed 2002, Chapter 2, Al-Subhi *et al.* 2003). Ascomata cover the agar in cultures of *C. tribiliformis prov. nom.*, while *C. moniliformis sensu lato* sporulates less prolifically and generally requires the addition of thiamine to enhance the production of ascomata (Robbins & Ma 1942, Hawker 1966, Upadhyay 1981). The growth of *C. tribiliformis prov. nom.* and *C. moniliformopsis* isolates is similar at 15 °C - 25 °C and both species have diminished growth at temperatures below 10 °C and above 30 °C. In contrast, *C. bhutanensis prov. nom.* isolates grow rapidly at temperatures below 10 °C and *C. omanensis prov. nom.* grows rapidly at temperatures above 30 °C. The optimum growth temperature for *C. moniliformis sensu lato* is 25 °C - 30 °C.

Sequence data for the ITS regions alone did not provide convincing separation between isolates of *C. bhutanensis prov. nom.*, *C. moniliformis*, *C. moniliformopsis*, *C. omanensis prov. nom.* and *C. tribiliformis prov. nom.* However, addition of sequences for the β -tubulin and EF1- α gene areas provided clear resolution of these five species into distinct clades with robust bootstrap and Bayesian support. These phylogenetic differences support the morphological and cultural differences observed between these species and emphasize the importance of considering multiple gene regions in taxonomic and phylogenetic studies.

Species of *Ceratocystis* reside in two distinct phylogenetic groups (Witthuhn *et al.* 1999). These include the *C. fimbriata* group where species are primary plant pathogens and the *C. coerulescens* group, where most species are not plant pathogens (Witthuhn *et al.* 1999). *Ceratocystis moniliformis sensu stricto* resides in the latter group and together with *C. bhutanensis prov. nom.*, *C. moniliformopsis*, *C. omanensis prov. nom.* and *C. tribiliformis prov. nom.* these are the only species in the *C. coerulescens* group with hat-shaped ascospores. For the purpose of this study these species are collectively known as *C. moniliformis sensu lato* as isolates of *C. bhutanensis prov. nom.* and *C. omanensis prov. nom.* were previously identified as *C. moniliformis*, because of their morphological similarities. Results of our phylogenetic study clearly showed that these three species are more closely related to each other than to any of the other *Ceratocystis* spp. within the *C. coerulescens* clade, suggesting that they originate from the same ancestor.

This study provides the first phylogenetic comparison for a collection of isolates, many of which have previously been treated as *C. moniliformis*. Clearly, *C. moniliformis sensu stricto* has a wide geographic distribution. Other apparently cryptic species that have emerged from this and other recent studies, however, appear to be restricted to specific geographic areas. Thus, *C. moniliformopsis* is found only in Australia (Yuan & Mohammed 2002), *C. bhutanensis prov. nom.* is associated with *Ips schmutzenhoferi* and found only in Bhutan, *C. omanensis prov. nom.* occurs in Oman and *C. tribiliformis prov. nom.* is restricted to Sumatra. Additional collections are likely to increase the distribution of some of these species but some, such as *C. bhutanensis prov. nom.*, appear to be ecologically adapted to their areas of origin and hosts. This study has also provided the first DNA sequence data showing that *C. moniliformopsis* represents a discrete species. It has also identified additional isolates of this species from mainland Australia, and from two different hosts.

Results of this study have shown clearly that the fungus that has for many years been treated as *C. moniliformis* represents a species complex. Recently, three new species, *C. bhutanensis prov. nom.*, *C. omanensis prov. nom.* and *C. moniliformopsis* thought to represent *C. moniliformis*, have been described as separate species (Yuan & Mohammed 2002, Chapter 2, Al-Alsubhi *et al.* 2003). In this study a fourth new species, *C. tribiliformis prov. nom.* has been recognised as belonging to the *C. moniliformis sensu lato* complex. We have included isolates from our own collections and others from various other sources. Given the high number of new species that have been recognised from a relatively small number of collections, it seems likely that additional new species will emerge as fungi resembling *C. moniliformis* are collected from various parts of the world.

Very little is known regarding the ecology of the species in the *C. moniliformis sensu lato* complex. Where inoculation experiments have been attempted (Davidson 1935), it has been concluded that the fungus is a wound inhabiting saprophyte. Now that additional species are being recognised, pathogenicity tests should be carried out with them, on their hosts of origin and in the areas where they have been found. This will lead to a greatly expanded understanding of the *C. moniliformis* species complex and possibly also the discovery of new pathogens.

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Table 1. Distribution and host range of *Ceratocystis moniliformis* causing staining.

Host	Geographical distribution	Reference
<i>Macaranga capensis</i>	South Africa	Van Wyk <i>et al.</i> 1991
<i>Theobroma</i> sp.	France	Paulin-Mahady <i>et al.</i> 2002
<i>Quercus robur</i>	Poland	Kowalski & Butin 1989
<i>Liquidamber styraciflua</i>	Texas, USA	Von Schrenk 1903
<i>Pinus ponderosa</i>	Texas, USA	Hedgcock 1906
<i>Pinus palustris</i> , <i>P. echinata</i> , <i>P. taeda</i> , <i>L. styraciflua</i> , <i>Liriodendron tulipifera</i> , <i>Nyssa aquatica</i> , <i>Fagus grandifolia</i> , <i>Magnolia</i> sp., <i>Quercus</i> sp.	USA	Davidson 1935
<i>F. crenata</i> , <i>Q. glandulifera</i> , <i>M. hypoleuca</i> , <i>Kalopanax ricinifolius</i> , <i>Pterocarya rhoifolia</i> , <i>Cercidiphyllum japonicum</i>	Tokyo	Kitajima 1936
<i>Quercus</i> sp.	Scotland	Bakshi 1951
<i>Pycnanthus kombo</i>	Cameroon	Luc 1952
<i>Theobromae</i> sp.	Madagascar	Luc 1952
<i>Calamus maximus</i> , <i>Endospermum peltatum</i> , <i>Parkia javanica</i>	Philippines	Roldan 1962
<i>Hevea</i> sp.	China	Witthuhn <i>et al.</i> 1999
<i>Erythrina</i> sp.	South Africa	Witthuhn <i>et al.</i> 1999

Table 2. Morphology of the teleomorph of *Ceratocystis moniliformis* as described by various authors.

<i>Character</i>	Hedgcock 1906	Davidson 1935	Kitajima 1936	Bakshi 1951	Luc 1952 Pycnanthi ^b	Luc 1952 Theobromae ^b	Hunt 1956	Roldan 1962	Upadhyay 1981
Colour	Brown/ black	Black	-	Transparent green tinge	Brown/ black	Dark brown	Black	Black	Brown/ black
Diameter	90 – 180	160 – 235	104 – 244	190 – 245	210 – 270	135 – 190	120 -160	150 – 250	90 – 210
Ornamentation	Conical spines (sparce), 12 – 16 x 6 (base)	Brown bristles, 18 – 60 x 3 – 4	Brown bristles (numerous), 85 – 124 long	2 types: (1) 65 x 1µm (2) 11 – 36 x 7 – 15 (Base) 2 – 3 (Tip)	Dark brown conical spines, 7 – 20 x 6 – 12 (Base)	Elongated, Setae, straight, 12 – 57 x 6 – 11 (Base), 2 – 4 (Tip)	Brown, short, conical spines, 30 x 8	Dark, hyaline tip, 10 – 65 x 2 – 3	Brown conical spines, 12 – 45 x 3 – 8 (Base)
Shape	Globose	Elongate/ pear- shaped	Flask-shaped/ spherical	Round/ elongate	Sub-spherical/ oval	Spherical/ elongated	Globose/ pear shaped	Globose/ Pear shaped	Globose/ Pear shaped
ASCOMATAL NECK									
Colour	-	Black	Black	Black	-	-	Black	Black	Black
Length	-	550 – 1000	305 – 609	731 – 896	600 – 900	500 – 700	900	920	550 – 1000
Width: base	-	30 – 36	-	39 – 52	29 – 42	21 – 30	20 – 30	20 – 45	20 – 35
Width: tip	-	14 – 15	-	14	16 – 19	10 – 13	10 – 15	10 – 14	11 – 15

^a All measurements were made in microns (µ).

^b Luc described *C. moniliformis* as having two different forms; the pycnanti and the theobromae from.

Table 2. Morphology of the teleomorph of *Ceratocystis moniliformis* as described by various authors (Continued)^a.

Character	Hedgecock 1906	Davidson 1935	Kitajima 1936	Bakshi 1951	Luc 1952 Pycnanthi ^b	Luc 1952 Theobromae ^b	Hunt 1956	Roldan 1962	Upadhyay 1981
Ostiolar hyphae	Brown-black, short, thick, 12 – 18 x 2	8 – 12 hyphae, hyaline, filaments 15 – 25	7 – 12 hyphae, hyaline, filaments 11 – 63	2 – 14 hyphae, hyaline, 34 – 41 x 2 – 3 (Base)	8 – 15 hyphae, hyaline setae, 19 – 46 x 2	7 – 12 hyphae, 12 – 21	8 – 10 hyphae, hyaline, 25 x 2	10 – 16 hyphae, hyaline, bent, 10 – 30 x 2	1 – 25 hyphae, hyaline, divergent, 2 – 3
ASCUS									
Colour	Hyaline	-	-	-	Barely visible	Poorly visible	Not seen	Evanescent	Not seen
ASCOSPORES									
Colour	Hyaline	-	Hyaline	Hyaline	Hyaline/ yellowish	Hyaline/ yellowish	-	-	Hyaline
Shape: side view	Oval, one side flat	Broad ovoid (hat)	Kidney shaped	Oval, brim (hat)	Oval, flattened	Oval, flattened	Hat- shaped	Hat- shaped	Oblong reniform
Length	4 – 5	4 – 5	2 – 4	6 – 8	4 – 6	4 – 5	3 – 6	4 – 6	-
Width	3 – 4	2 – 3	4 – 5	3 – 4	3 – 5	3 – 5	2 – 3	3 – 4	-
Texture	Long, slimy, grey mass	Gelatinous sheath	Mucilagi-nous substance	Oval globule, mucilaginous	Pinkish yellow in mass	Pinkish yellow in mass	Gelati-nous sheath	Gelati-nous sheath	Gelatinous sheath

^a All measurements were made in microns (μ).

^b Luc described *C. moniliformis* as having two different forms; the pycanti and the theobromae from.

Table 3. Morphology of the anamorph state of *Ceratocystis moniliformis* as described by various authors ^a.

Character	Hedgcock 1906	Davidson 1935	Kitajima 1936	Bakshi 1951	Luc 1952 Pycnanthi ^b	Luc 1952 Theobromae ^b	Hunt 1956	Roldan 1962	Upadhyay 1981
CONIDIOPHORES									
Length	-	(1) 3 (2) 5–6	(1) 28–30 (2) 63–70	7–14	18–52	33–65	(1) 60 (2) 35	100	18–77
Width	-	-	(1) 5 (2) 7–8	(1) 4–9 (2) 5	7–8	4–5	(1) 4–6 (2) 6	4–6	2–3
CONIDIA									
Shape	Cylindrical	(1) Cylindrical (2) Barrel	(1) Cylindrical (2) Barrel	Cylindrical	Cylindrical to barrel	Cylindrical	(1) Cylindrical (2) Barrel	Cylindrical	(1) Cylindrical (2) Shorter
Length	6–8	(1) 6–10 (2) 5–7	(1) 7–8 (2) 8–14	4–16	5–8	6–20	(1) 6–19 (2) 6–9	6–20	(1) 16–20 (2) 6–9
Width	2	(1) 3 (2) 5–6	(1) 1–2 (2) 7–10	1–2	2–4	2–4	(1) 2–3 (2) 4–6	2–4	(1) 2–3 (2) 4–6
CULTURE									
Growth rate	-	38 mm in 5 days	-	60mm in 10 days	-	-	45 mm in 5 days	25 mm in 5 days	70 mm in 12 days
Colour	Hyaline / grey /black	Hyaline / light brown	Hyaline / light brown	Hyaline / light brown	Hyaline / brown	-	White / grey / brown	White / brown	Hyaline / pale brown
Odour	-	Banana oil	-	Pear-drops	-	Ethyl acetate	Banana oil	Banana oil	Banana oil
Mycelium width	2–8	-	2–3	2–5	3–7	2–4	2–8	2–4	2–8

^a All measurements were made in microns (μ).^b Luc described *C. moniliformis* as having two different forms; the pycanti and the theobromae from.

Table 4. *Ceratocystis* isolates used in this study.

<i>Ceratocystis</i> spp.	Isolate no. ^d	Alternative numbers ^{e, f}	GenBank accession nr.	Date of isolation	Host	Geographical origin	Associated insect	Collector(s)
<i>C. moniliformis</i>	CMW 13011 ^a		AY528991 ^g AY529001 ^h AY529012 ⁱ	1996	<i>Quercus</i> sp.	Sumatra, Indonesia	None	M.J. Wingfield
"	CMW 13012 ^{a, b}		AY528992 ^g AY529002 ^h AY529013 ⁱ	"	"	"	"	"
"	CMW 13013 ^{a, b, c}		AY528993 ^g AY529003 ^h AY529014 ⁱ	"	"	"	"	"
"	CMW 13015 ^{a, b, c}		AY528994 ^g AY529004 ^h AY529015 ⁱ	"	"	"	"	"
"	CMW 9590 ^{a, c}		AY528985 ^g AY528996 ^h AY529006 ⁱ	2002	<i>Eucalyptus grandis</i>	Mpumalanga, South Africa	"	J. Roux
"	CMW 10134 ^{a, c}		N/A	"	"	"	"	M. van Wyk
"	CMW 4114 ^a		AY528986 ^g AY528997 ^h AY529007 ⁱ	1997	<i>Schizolobium parahybum</i>	Ecuador, South America	"	M. J. Wingfield
"	CMW 9990 ^a	CBS 155.62	N/A	1962	<i>Theobroma cacao</i>	Costa Rica	"	A. J. Hansen
"	CMW 8379 ^a		AY528995 ^g AY529005 ^h AY529016 ⁱ	2001	<i>Cassia fistula</i>	Punaka, Bhutan	"	M. J. Wingfield, T. Kirisits & D. B. Chhetri
"	CMW 8240 ^a		AY528989 ^g AY529000 ^h AY529010 ⁱ	"	"	Wangdi, Bhutan	"	"
"	CMW 8238 ^c		N/A	"	"	"	"	"
<i>C. moniliformopsis</i>	CMW 9986 ^{a, c}	CBS 109441	AY528987 ^g AY528998 ^h AY529008 ⁱ	1999	<i>Eucalyptus obliqua</i>	Tazmania, Australia	"	Z. Q. Yuan
"	CMW 10214 ^{a, c}		AY528988 ^g AY528999 ^h AY529009 ⁱ	1989	<i>E. sieberi</i>	"	"	M. J. Dudzinski

Table 4. *Ceratocystis* isolates used in this study (Continued).

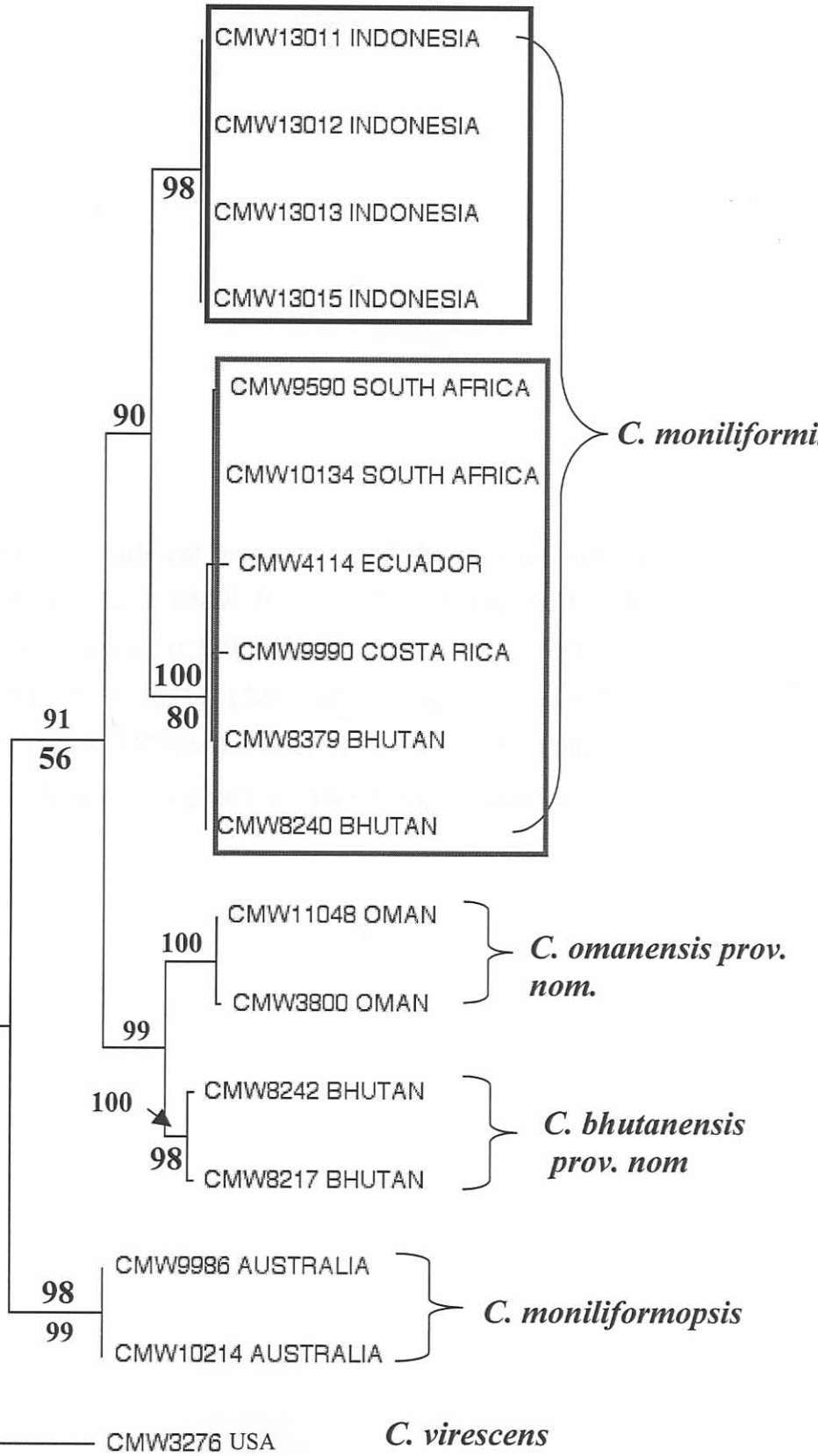
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<i>Ceratocystis</i> spp.	Isolate no. ^d	Alternative numbers ^{e, f}	GenBank accession nr.	Date of isolation	Host	Geographical origin	Associated insect	Collector(s)
<i>C. bhutanensis</i>	CMW 8217 ^{a, c}	PREM 57807	AY528952 ^g AY528957 ^h AY528962 ⁱ	2001	<i>Pinus spinulosa</i>	Jeleka, Bhutan	<i>Ips schmutzen-hoferi</i>	M. J. Wingfield, T. Kirisits & D. B. Chhetri
"	CMW 8242 ^a	CBS 112907	AY528951 ^g AY528956 ^h AY528961 ⁱ	2001	<i>Pinus spinulosa</i>	Jeleka, Bhutan	<i>Ips schmutzenhoferi</i>	"
"	CMW 8244 ^c	PREM 57811	N/A	"	"	"	"	"
"	CMW 8241 ^c	PREM 57808	N/A	"	"	"	"	"
<i>C. omanensis</i>	CMW 11048 ^{a, c}	None	N/A	2003	<i>Mangifera</i> sp.	Oman	<i>Cryphalus scabrecollis</i>	A. Al-Adawi
"	CMW 3800 ^a	"	N/A	"	"	"	"	"
<i>C. virescens</i>	CMW 3276 ^a	"	AY528984 ^g AY528990 ^h AY528991 ⁱ	1963	<i>Quercus</i> sp.	N.Y., USA	None	Hinds, T.

^{a, b, c, d, e, f, g, h, i} Isolates marked with ^a were sequenced, those marked with ^b were used for morphological descriptions and those marked with ^c were included in the growth studies, ^d CMW refers to the culture collection of the Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa. ^e CBS refers to the Centraalbureau voor Schimmelcultures, Utrecht, The Netherlands, ^f PREM to the National Fungal Herbarium (PREM), Pretoria, South Africa. GenBank accession numbers that are marked with ^g represents the ITS sequences, those marked with an ^h represent the β -tubulin sequences and those marked with a ⁱ represent the elongation factor sequences.



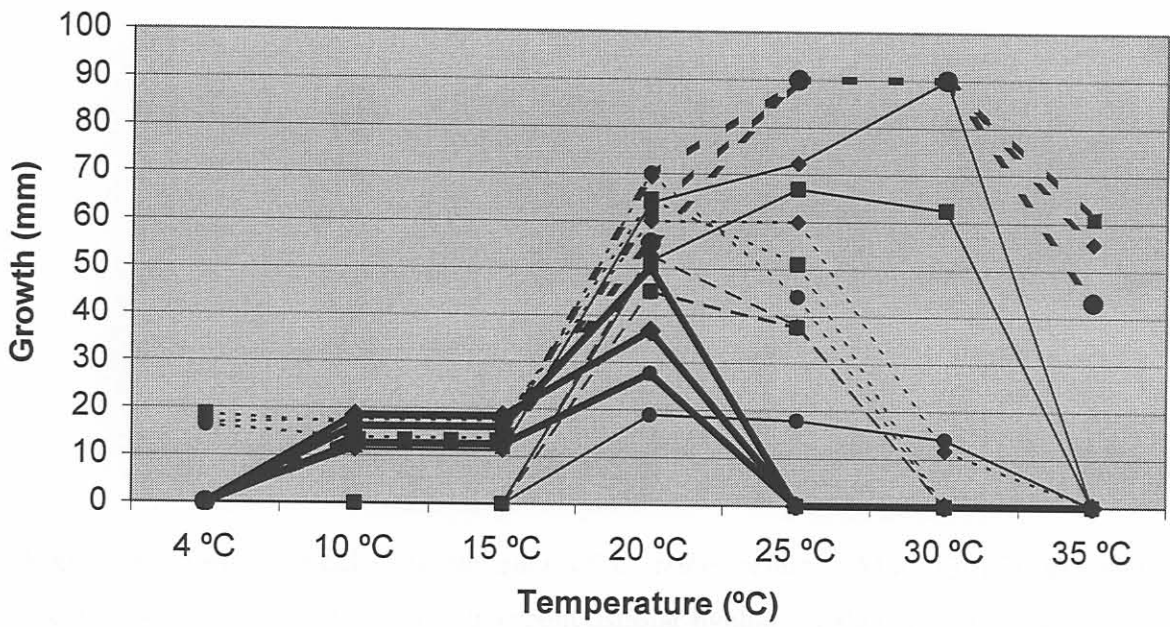
Figure 1. A phylogenetic tree based on the combined sequence data from three gene regions; ITS, β -tubulin and EF1- α , showing the monophyletic nature of *C. moniliformis* sensu lato. The phylogram was obtained using the heuristic search option based on parsimony. Bootstrap values are indicated above the branches and Bayesian values are indicated below the branches. *Ceratocystis virescens* was treated as the out-group.



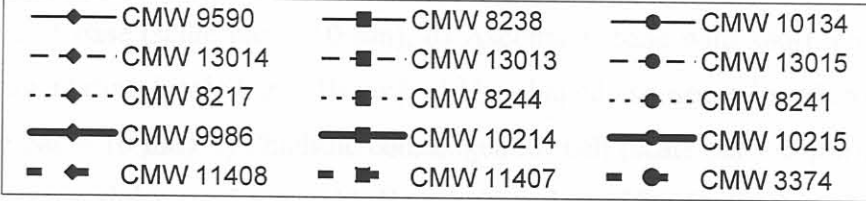
— 10 changes



Figure 2. Graphs of growth at 7 different temperatures of the four different species, *C. moniliformis* (CMW 9590, CMW 8238, CMW 10134, CMW 13014, CMW 13013, CMW 13015), *C. bhutanensis prov. nom.* (CMW 8217, CMW 8244, CMW 8241), *C. moniliformopsis* (CMW 9986, CMW 10214, CMW 10215) and *C. omanensis prov. nom.* (CMW 11408, CMW 11407, CMW 3374) tested after 72 hours of incubation. The standard deviation for each isolate at all seven temperatures respectively, are indicated in the table below the graph.

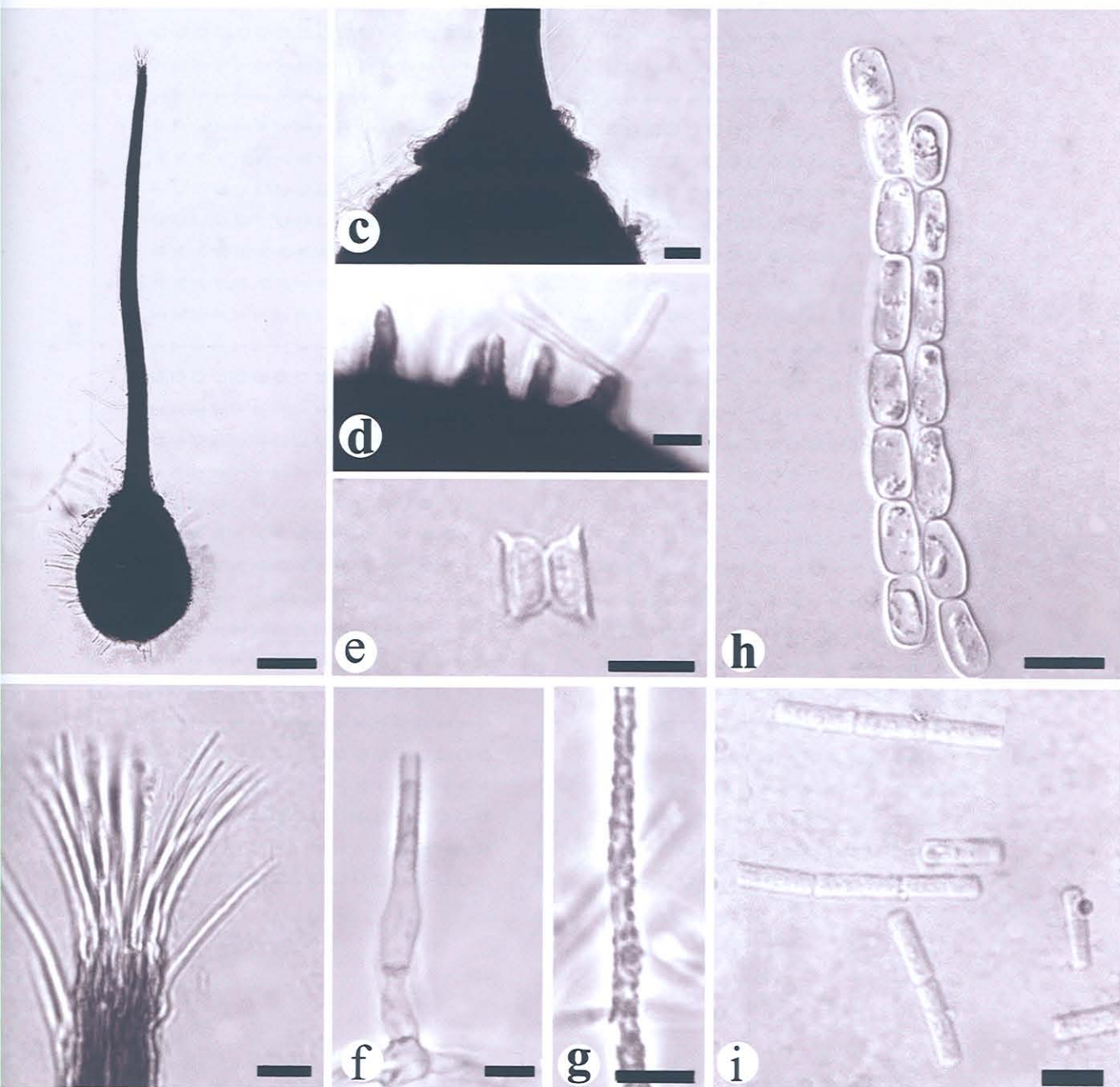


C. moniliformis
"
C. bhutanensis
C. moniliformopsis
C. omanensis



Temperature/ Isolate	4 °C	10 °C	15 °C	20 °C	25 °C	30 °C	35 °C
CMW 9590	0.0	3.2	3.2	1.9	0.8	0.0	0.0
CMW 8238	0.0	0.0	0.0	2.4	1.4	2.9	0.0
CMW 10134	0.0	0.0	0.0	4.1	5.0	3.4	0.0
CMW 13014	0.0	0.0	0.0	3.0	2.1	0.0	0.0
CMW 13013	0.0	0.0	0.0	1.9	2.7	0.0	0.0
CMW 13015	0.0	0.0	0.0	1.7	2.4	0.0	0.0
CMW 8217	1.3	0.5	0.5	3.9	3.7	2.0	0.0
CMW 8244	1.1	0.6	0.6	7.3	3.2	0.0	0.0
CMW 8241	0.6	0.8	0.8	5.1	4.1	0.0	0.0
CMW 9986	0.0	1.7	1.8	1.1	0.0	0.0	0.0
CMW 10214	0.0	6.6	6.6	0.7	0.0	0.0	0.0
CMW 12215	0.0	1.2	1.2	5.8	0.0	0.0	0.0
CMW 11408	0.0	2.7	2.7	1.9	0.0	0.0	1.1
CMW 11407	0.0	2.4	2.4	7.0	0.0	0.0	7.2
CMW 3374	0.0	2.3	2.3	7.4	0.0	0.0	16.6

Figure 3. Morphological characteristics of *C. tribiliformis* (CMW 13015). a) Obpyriform ascoma (scale bar = 100 μm), b) Divergent ostiolar hyphae (scale bar = 10 μm), c) Ascomatal neck disc-shaped at base (scale bar = 10 μm), d) Ascomatal base with short, conical spines and hyphal ornamentation (scale bar = 10 μm), e) Hat-shaped ascospore in side view, oval in face view (scale bar = 10 μm), f) Phialidic conidiogenous cell (scale bar = 5 μm), g) Hyphae with rough edges (scalebar = 5 μm), h) Barrel-shaped conidia (scale bar = 10 μm), i) Cylindrical conidia (scale bar = 10 μm).



APPENDIX

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ITS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50				
CMW 13011 <i>C. tribiliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 13012 <i>C. tribiliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 13013 <i>C. tribiliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 13015 <i>C. tribiliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 11048 <i>C. calidophila</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 3800 <i>C. calidophila</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 8242 <i>C. bhutanensis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 8217 <i>C. bhutanensis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 9590 <i>C. moniliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 10134 <i>C. moniliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 4114 <i>C. moniliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 9990 <i>C. moniliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 8240 <i>C. moniliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 8379 <i>C. moniliformis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 9986 <i>C. moniliformopsis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 10214 <i>C. moniliformopsis</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	G	T	T	A	A	C	C	A	T	T	T	G	T	G	A	A	T	T	T	T	A	A	C	C	A	T	T	T	T	G	T	G	A	A	T	T	T	A
CMW 3276 <i>C. virescens</i>	C	T	G	A	G	T	T	T	T	T	A	A	C	T	C	T	-	T	A	A	A	C	C	A	T	A	T	G	A	A	C	A	A	T	T	T	A	A	C	C	A	T	A	T	G	A	A	C	A	T	A			

ITS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50																				
CMW 13011 <i>C. tribiliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A
CMW 13012 <i>C. tribiliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 13013 <i>C. tribiliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 13015 <i>C. tribiliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 11048 <i>C. calidophila</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	T	-	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	T	-	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 3800 <i>C. calidophila</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	T	-	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	T	-	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 8242 <i>C. bhutanensis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	-	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	-	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 8217 <i>C. bhutanensis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	-	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	-	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 9590 <i>C. moniliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 10134 <i>C. moniliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 4114 <i>C. moniliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	-	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 9990 <i>C. moniliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 8240 <i>C. moniliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 8379 <i>C. moniliformis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 9986 <i>C. moniliformopsis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	T	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 10214 <i>C. moniliformopsis</i>	C	C	A	A	A	C	A	T	G	A	A	C	T	G	C	A	T	A	C	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	A	C	C	A	T	G	A	A	C	T	G	C	A	T	A	T	G	G	C	G	G	G	T	C	T	C	C	C	-	G	C	C	A	
CMW 3276 <i>C. virescens</i>	C	C	T	A	T	T	A	G	C	T	G	C	T	T	T	G	G	C	A	G	G	C	T	T	G	T	A	A	C	A</																																								

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	80										90										100																
CMW 13011 <i>C. tribiliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	T	-	-	-	A	T	A	T
CMW 13012 <i>C. tribiliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	T	-	-	-	A	T	A	T
CMW 13013 <i>C. tribiliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 13015 <i>C. tribiliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 11048 <i>C. calidophila</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 3800 <i>C. calidophila</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 8242 <i>C. bhutanensis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 8217 <i>C. bhutanensis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 9590 <i>C. moniliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 10134 <i>C. moniliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 4114 <i>C. moniliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 9990 <i>C. moniliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 8240 <i>C. moniliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 8379 <i>C. moniliformis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 9986 <i>C. moniliformopsis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 10214 <i>C. moniliformopsis</i>	G	-	-	-	C	A	G	T	A	C	T	C	T	T	G	-	-	-	A	A	C	T	C	G	T	T	T	T	T	-	-	-	A	T	A	T	
CMW 3276 <i>C. virescens</i>	C	T	G	C	C	G	G	T	A	G	T	A	T	T	T	T	A	A	A	A	C	T	C	T	T	T	T	T	T	T	T	A	T	T	C	T	

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	110										120										130										140									
CMW 13011 <i>C. tribiliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	T	A	T	A	A	A				
CMW 13012 <i>C. tribiliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	T	A	T	A	A	A				
CMW 13013 <i>C. tribiliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 13015 <i>C. tribiliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 11048 <i>C. calidophila</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	C	C	A	T	T	T	A	T	A	A	A					
CMW 3800 <i>C. calidophila</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 8242 <i>C. bhutanensis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 8217 <i>C. bhutanensis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 9590 <i>C. moniliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 10134 <i>C. moniliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 4114 <i>C. moniliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 9990 <i>C. moniliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 8240 <i>C. moniliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 8379 <i>C. moniliformis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 9986 <i>C. moniliformopsis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 10214 <i>C. moniliformopsis</i>	A	A	A	G	A	A	T	T	T	A	T	T	C	A	T	T	G	C	T	G	A	G	T	A	G	C	A	T	T	T	A	T	A	A	A					
CMW 3276 <i>C. virescens</i>	A	A	A	G	A	A	T	T	-	A	T	T	C	A	T	T	G	C	T	G	A	G	T	G	G	C	A	T	T	A	A	C	A	T	A	A				

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CMW 13011 <i>C. tribiliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 13012 <i>C. tribiliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 13013 <i>C. tribiliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 13015 <i>C. tribiliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 11048 <i>C. calidophila</i>	C	T	-	G	A	A	A	T	G	C	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 3800 <i>C. calidophila</i>	C	T	-	G	A	A	A	T	G	C	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 8242 <i>C. bhutanensis</i>	C	T	-	G	A	A	A	T	G	C	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 8217 <i>C. bhutanensis</i>	C	T	-	G	A	A	A	T	G	C	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 9590 <i>C. moniliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 10134 <i>C. moniliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 4114 <i>C. moniliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 9990 <i>C. moniliformis</i>	C	T	-	G	A	A	A	T	G	C	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 8240 <i>C. moniliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 8379 <i>C. moniliformis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 9986 <i>C. moniliformopsis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 10214 <i>C. moniliformopsis</i>	C	T	-	G	A	A	A	T	G	T	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C
CMW 3276 <i>C. virescens</i>	A	C	C	G	A	A	A	T	G	C	A	T	C	G	G	C	T	G	T	G	T	T	A	C	A	T	G	C	A	G	T	T	T	C	C	C

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CMW 13011 <i>C. tribiliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 13012 <i>C. tribiliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 13013 <i>C. tribiliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 13015 <i>C. tribiliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 11048 <i>C. calidophila</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	T	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 3800 <i>C. calidophila</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	T	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 8242 <i>C. bhutanensis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	T	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 8217 <i>C. bhutanensis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	T	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 9590 <i>C. moniliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 10134 <i>C. moniliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 4114 <i>C. moniliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 9990 <i>C. moniliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 8240 <i>C. moniliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 8379 <i>C. moniliformis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 9986 <i>C. moniliformopsis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 10214 <i>C. moniliformopsis</i>	T	G	T	G	T	A	G	T	A	A	A	A	A	C	T	T	T	A	C	T	G	T	T	G	C	A	C	T	T	T	G	A	A	A	T	T	C
CMW 3276 <i>C. virescens</i>	T	G	T	G	T	A	G	T	A	A	-	-	-	T	A	T	C	T	A	T	A	T	T	A	C	A	C	T	T	T	G	A	A	A	C	T	C

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CMW 13011 <i>C. tribiliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 13012 <i>C. tribiliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 13013 <i>C. tribiliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 13015 <i>C. tribiliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 11048 <i>C. calidophila</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 3800 <i>C. calidophila</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	T	T	T	G	T	A	A	G	T	T	C	-	-	-	
CMW 8242 <i>C. bhutanensis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	T	T	T	G	T	A	A	G	T	T	-	-	-	-	
CMW 8217 <i>C. bhutanensis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	T	T	T	G	T	A	A	G	T	T	C	-	-	-	
CMW 9590 <i>C. moniliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 10134 <i>C. moniliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 4114 <i>C. moniliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 9990 <i>C. moniliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 8240 <i>C. moniliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 8379 <i>C. moniliformis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	A	T	-	-	
CMW 9986 <i>C. moniliformopsis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	T	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	T
CMW 10214 <i>C. moniliformopsis</i>	G	C	T	A	C	C	T	G	A	C	C	T	G	T	C	T	G	C	C	A	T	C	T	T	G	T	A	A	G	T	T	T
CMW 3276 <i>C. virescens</i>	G	C	T	A	C	C	T	G	A	C	T	T	G	C	T	C	T	G	C	T	A	T	C	T	T	G	T	A	T	G	T	T

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CMW 13011 <i>C. tribiliformis</i>	-	-	-	-	-	-	C	T	T	T	T	-	G	T	T	T	G	T	A	G	G	A	T	T	T	G	G	A	G	C	A	T				
CMW 13012 <i>C. tribiliformis</i>	-	-	-	-	-	-	C	T	T	T	T	-	G	T	T	T	G	T	A	G	G	A	T	T	T	G	G	A	G	C	A	T				
CMW 13013 <i>C. tribiliformis</i>	-	-	-	-	-	-	C	T	T	T	T	-	G	T	T	T	G	T	A	G	G	A	T	T	T	G	G	A	G	C	A	T				
CMW 13015 <i>C. tribiliformis</i>	-	-	-	-	-	-	C	T	T	T	T	-	G	T	T	T	G	T	A	G	G	A	T	T	T	G	G	A	G	C	A	T				
CMW 11048 <i>C. calidophila</i>	-	-	-	-	-	-	C	T	T	T	T	C	C	C	T	G	C	A	T	C	A	T	A	T	T	T	G	G	A	G	T	A	T			
CMW 3800 <i>C. calidophila</i>	-	-	-	-	-	-	C	T	T	T	T	C	C	C	T	G	C	A	T	C	A	T	A	T	T	T	G	G	A	G	T	A	T			
CMW 8242 <i>C. bhutanensis</i>	-	-	-	-	-	-	C	T	T	C	T	C	C	C	T	G	C	A	T	C	A	T	A	C	T	T	G	G	A	G	T	A	T			
CMW 8217 <i>C. bhutanensis</i>	-	-	-	-	-	-	C	T	T	C	T	C	C	C	T	G	C	A	T	C	A	T	A	C	T	T	G	G	A	G	T	A	T			
CMW 9590 <i>C. moniliformis</i>	-	-	-	-	-	-	C	T	T	T	T	C	-	-	T	T	T	G	T	A	G	T	A	T	T	T	G	G	A	G	C	A	T			
CMW 10134 <i>C. moniliformis</i>	-	-	-	-	-	-	C	T	T	T	T	C	-	-	T	T	T	G	T	A	G	T	A	T	T	T	G	G	A	G	C	A	T			
CMW 4114 <i>C. moniliformis</i>	-	-	-	-	-	-	C	T	T	T	T	C	-	-	T	T	T	G	T	A	G	T	A	T	T	T	G	G	A	G	C	A	T			
CMW 9990 <i>C. moniliformis</i>	-	-	-	-	-	-	C	T	T	T	T	C	-	-	T	T	T	G	T	A	G	T	A	T	T	T	G	G	A	G	C	A	T			
CMW 8240 <i>C. moniliformis</i>	-	-	-	-	-	-	C	T	T	T	T	C	-	-	T	T	T	G	T	A	G	T	A	T	T	T	G	G	A	G	C	A	T			
CMW 8379 <i>C. moniliformis</i>	-	-	-	-	-	-	C	T	T	T	T	C	-	-	T	T	T	G	T	A	G	T	A	T	T	T	G	G	A	G	C	A	T			
CMW 9986 <i>C. moniliformopsis</i>	T	T	G	G	A	G	G	A	A	C	T	T	T	T	C	-	G	T	T	T	C	-	A	-	T	A	T	T	T	G	G	A	G	C	A	-
CMW 10214 <i>C. moniliformopsis</i>	T	T	G	G	A	G	G	A	A	C	T	T	T	T	C	-	G	T	T	T	C	-	A	-	T	A	T	T	T	G	G	A	G	C	A	-
CMW 3276 <i>C. virescens</i>	-	-	-	C	A	C	C	A	A	C	T	-	-	-	-	-	-	-	-	A	-	T	A	T	T	T	G	-	T	C	T	A	T	T		

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CMW 13011 <i>C. tribiliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	C	-	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 13012 <i>C. tribiliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	C	-	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 13013 <i>C. tribiliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	C	-	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 13015 <i>C. tribiliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	C	-	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 11048 <i>C. calidophila</i>	C	A	T	T	C	A	C	T	A	A	C	A	T	T	C	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 3800 <i>C. calidophila</i>	C	A	T	T	C	A	C	T	A	A	C	A	T	T	C	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	-	-	-	-	-	-
CMW 8242 <i>C. bhutanensis</i>	C	A	T	T	C	A	C	T	A	A	C	A	T	T	C	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	-	-	-	-	-	-
CMW 8217 <i>C. bhutanensis</i>	C	A	T	T	C	A	C	T	A	A	C	A	T	T	C	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	-	-	-	-	-	-
CMW 9590 <i>C. moniliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	T	C	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	-	-	-	-	-	-
CMW 10134 <i>C. moniliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	-	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 4114 <i>C. moniliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	-	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 9990 <i>C. moniliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	-	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 8240 <i>C. moniliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	-	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 8379 <i>C. moniliformis</i>	G	A	T	T	C	A	C	T	A	A	C	A	T	-	-	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 9986 <i>C. moniliformopsis</i>	C	A	T	T	G	A	C	T	A	A	C	A	T	A	T	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	C	T	-	-	-	-
CMW 10214 <i>C. moniliformopsis</i>	C	A	T	T	G	A	C	T	A	A	C	A	T	A	T	A	T	T	T	T	C	-	-	-	-	-	-	T	C	T	-	-	-	-	-	-	-	-	-	-
CMW 3276 <i>C. virescens</i>	C	A	T	T	-	A	G	T	-	-	-	T	T	A	T	A	T	T	T	T	G	C	A	T	G	G	A	T	C	T	T	T	G	C	T	A	A			

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CMW 13011 <i>C. tribiliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 13012 <i>C. tribiliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 13013 <i>C. tribiliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 13015 <i>C. tribiliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 11048 <i>C. calidophila</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 3800 <i>C. calidophila</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 8242 <i>C. bhutanensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 8217 <i>C. bhutanensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 9590 <i>C. moniliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 10134 <i>C. moniliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 4114 <i>C. moniliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 9990 <i>C. moniliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 8240 <i>C. moniliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 8379 <i>C. moniliformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 9986 <i>C. moniliformopsis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 10214 <i>C. moniliformopsis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	G	C	C	G	T	G	G	T	A	A	G	G				
CMW 3276 <i>C. virescens</i>	C	A	C	C	T	C	T	T	T	C	T	T	C	G	T	C	T	T	T	A	T	T	A	G	C	C	G	T	G	G	T	A	A	G	G

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CMW 13011 <i>C. tribiliformis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 13012 <i>C. tribiliformis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 13013 <i>C. tribiliformis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 13015 <i>C. tribiliformis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 11048 <i>C. calidophila</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	C	C	T	G	T	G	C	T	C	C	A	T	T	C	C
CMW 3800 <i>C. calidophila</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	C	C	T	G	T	G	C	T	C	C	A	T	T	C	C
CMW 8242 <i>C. bhutanensis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	C	C	T	G	T	G	C	T	C	C	A	T	T	C	C
CMW 8217 <i>C. bhutanensis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	C	C	T	G	T	G	C	T	C	C	A	T	T	C	C
CMW 9590 <i>C. moniliformis</i>	T	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 10134 <i>C. moniliformis</i>	T	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 4114 <i>C. moniliformis</i>	T	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 9990 <i>C. moniliformis</i>	T	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 8240 <i>C. moniliformis</i>	T	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 8379 <i>C. moniliformis</i>	T	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	T	T	G	C	T	C	C	A	T	T	C	C
CMW 9986 <i>C. moniliformopsis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	C	T	G	C	T	C	C	A	T	T	C	C
CMW 10214 <i>C. moniliformopsis</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	C	G	C	T	C	T	C	T	G	C	T	C	C	A	T	T	C	C
CMW 3276 <i>C. virescens</i>	C	C	C	C	A	A	C	A	A	C	G	T	C	C	A	G	A	C	T	G	C	C	C	T	G	T	G	C	T	C	C	A	T	T	C	C

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CMW 13011 <i>C. tribiliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	A	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 13012 <i>C. tribiliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	A	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 13013 <i>C. tribiliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	A	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 13015 <i>C. tribiliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	A	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	T	G	G
CMW 11048 <i>C. calidophila</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	T	G	G
CMW 3800 <i>C. calidophila</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	T	G	G
CMW 8242 <i>C. bhutanensis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	T	G	G
CMW 8217 <i>C. bhutanensis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	A	T	T	C	G	T	T	G	G
CMW 9590 <i>C. moniliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 10134 <i>C. moniliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 4114 <i>C. moniliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 9990 <i>C. moniliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 8240 <i>C. moniliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 8379 <i>C. moniliformis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	G	A	C	C	T	T	C	G	T	C	G	G
CMW 9986 <i>C. moniliformopsis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	C	A	C	C	T	T	C	G	T	C	G	G
CMW 10214 <i>C. moniliformopsis</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	T	T	C	C	A	C	C	T	T	C	G	T	C	G	G
CMW 3276 <i>C. virescens</i>	T	C	C	C	C	G	T	G	G	C	C	T	C	A	A	G	A	T	G	T	C	G	T	C	T	A	C	C	T	T	C	G	T	C	G	G

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CMW 13011 <i>C. tribiliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	T	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 13012 <i>C. tribiliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	T	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 13013 <i>C. tribiliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	T	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 13015 <i>C. tribiliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	T	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 11048 <i>C. calidophila</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	G	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 3800 <i>C. calidophila</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	G	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 8242 <i>C. bhutanensis</i>	T	A	A	C	T	C	T	A	C	T	G	C	T	A	T	C	C	A	G	G	A	G	C	T	G	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 8217 <i>C. bhutanensis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	G	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T	T	A	A	G	C	G	C	A	T
CMW 9590 <i>C. moniliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 10134 <i>C. moniliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 4114 <i>C. moniliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 9990 <i>C. moniliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 8240 <i>C. moniliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 8379 <i>C. moniliformis</i>	T	A	A	C	T	C	T	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 9986 <i>C. moniliformopsis</i>	T	A	A	C	T	C	T	A	C	T	G	C	T	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 10214 <i>C. moniliformopsis</i>	T	A	A	C	T	C	T	A	C	T	G	C	T	A	T	C	C	A	G	G	A	G	C	T	C	T	T	C	A	A	G	C	G	C	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T
CMW 3276 <i>C. virescens</i>	T	A	A	C	T	C	G	A	C	T	G	C	C	A	T	C	C	A	G	G	A	G	C	T	G	T	T	C	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T	T	A	A	G	C	G	T	A	T

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CMW 13011 <i>C. tribiliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 13012 <i>C. tribiliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 13013 <i>C. tribiliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 13015 <i>C. tribiliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 11048 <i>C. calidophila</i>	T	G	G	T	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 3800 <i>C. calidophila</i>	T	G	G	T	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 8242 <i>C. bhutanensis</i>	T	G	G	T	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 8217 <i>C. bhutanensis</i>	T	G	G	T	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 9590 <i>C. moniliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 10134 <i>C. moniliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 4114 <i>C. moniliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 9990 <i>C. moniliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 8240 <i>C. moniliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 8379 <i>C. moniliformis</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 9986 <i>C. moniliformopsis</i>	T	G	G	T	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 10214 <i>C. moniliformopsis</i>	T	G	G	T	G	A	G	C	A	G	T	T	C	A	C	T	G	C	C	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C
CMW 3276 <i>C. virescens</i>	T	G	G	C	G	A	G	C	A	G	T	T	C	A	C	T	G	C	T	A	T	G	T	T	C	C	G	T	C	G	C	A	A	G	G	C	T	A	A	G	G	C

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CMW 13011 <i>C. tribiliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 13012 <i>C. tribiliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 13013 <i>C. tribiliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 13015 <i>C. tribiliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 11048 <i>C. calidophila</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 3800 <i>C. calidophila</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 8242 <i>C. bhutanensis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 8217 <i>C. bhutanensis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 9590 <i>C. moniliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 10134 <i>C. moniliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 4114 <i>C. moniliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 9990 <i>C. moniliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 8240 <i>C. moniliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 8379 <i>C. moniliformis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 9986 <i>C. moniliformopsis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 10214 <i>C. moniliformopsis</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	A	A	C	G	A	G	G	G	T	A	T	G	G	A	C	G	A
CMW 3276 <i>C. virescens</i>	T	T	T	C	T	T	G	C	A	T	T	G	G	T	A	C	A	C	T	G	G	T	G	A	G	G	G	T	A	T	G	G	A	C	G	A

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CMW 13011 <i>C. tribiliformis</i>	A	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	T	A	A	T	C	C	C	C	G	C	C	G	A	T	A
CMW 13012 <i>C. tribiliformis</i>	A	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	T	A	A	T	C	C	C	C	G	C	C	G	A	T	A
CMW 13013 <i>C. tribiliformis</i>	A	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	T	A	A	T	C	C	C	C	G	C	C	G	A	T	A
CMW 13015 <i>C. tribiliformis</i>	A	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	T	A	A	C	T	A	T	C	C	C	C	G	C	C	G	A	C	A	
CMW 11048 <i>C. calidophila</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	T	A	A	C	T	A	T	C	C	C	C	G	C	C	G	A	C	A	
CMW 3800 <i>C. calidophila</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	T	A	T	C	C	C	C	G	C	C	G	A	C	A	
CMW 8242 <i>C. bhutanensis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	T	C	C	C	G	C	C	G	A	C	A	
CMW 8217 <i>C. bhutanensis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	T	C	C	C	G	C	C	G	A	C	A	
CMW 9590 <i>C. moniliformis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	A	C	C	C	G	C	C	G	A	T	A	
CMW 10134 <i>C. moniliformis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	A	C	C	C	G	C	C	G	A	T	A	
CMW 4114 <i>C. moniliformis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	A	C	C	C	C	G	C	C	G	A	T	A
CMW 9990 <i>C. moniliformis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
CMW 8240 <i>C. moniliformis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	T	C	C	C	G	C	C	G	A	T	A	
CMW 8379 <i>C. moniliformis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	T	C	C	C	G	C	C	G	A	C	A	
CMW 9986 <i>C. moniliformopsis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	T	C	C	C	G	C	C	G	A	C	A	
CMW 10214 <i>C. moniliformopsis</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	A	A	A	C	C	A	A	C	A	C	C	C	G	C	C	G	A	C	A
CMW 3276 <i>C. virescens</i>	G	A	T	G	G	A	G	T	T	C	A	C	T	G	A	G	G	C	A	T	C	C	A	G	T	C	T	T	A	C	A	T	A	T	A	T	A	

	1090										1100										1110															
CMW 13011 <i>C. tribiliformis</i>	G	T	A	T	A	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T	
CMW 13012 <i>C. tribiliformis</i>	G	T	A	T	A	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 13013 <i>C. tribiliformis</i>	G	T	A	T	A	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 13015 <i>C. tribiliformis</i>	G	T	A	T	A	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 11048 <i>C. calidophila</i>	G	T	A	T	A	G	A	G	G	T	T	G	A	G	C	T	G	A	T	T	T	T	G	A	C	G	A	G	G	C	A	G	C	C	C	T
CMW 3800 <i>C. calidophila</i>	G	T	A	T	A	G	A	G	G	T	T	G	A	G	C	T	G	A	T	T	T	T	G	A	C	G	A	G	G	C	A	G	C	C	C	T
CMW 8242 <i>C. bhutanensis</i>	G	T	A	T	A	A	A	G	G	T	T	G	A	G	T	T	G	A	T	T	T	T	C	A	T	G	A	G	G	C	A	G	C	C	C	T
CMW 8217 <i>C. bhutanensis</i>	G	T	A	T	A	A	A	G	G	T	T	G	A	G	T	T	G	A	T	T	T	T	C	A	T	G	A	G	G	C	A	G	C	C	C	T
CMW 9590 <i>C. moniliformis</i>	G	T	A	T	G	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 10134 <i>C. moniliformis</i>	G	T	A	T	G	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 4114 <i>C. moniliformis</i>	G	T	A	T	G	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 9990 <i>C. moniliformis</i>	G	T	A	T	G	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 8240 <i>C. moniliformis</i>	G	T	A	T	A	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 8379 <i>C. moniliformis</i>	G	T	A	T	G	G	A	G	G	T	T	G	A	G	T	T	G	T	T	T	T	T	G	A	T	G	A	G	G	C	A	A	T	A	C	T
CMW 9986 <i>C. moniliformopsis</i>	G	C	A	A	A	G	A	G	G	T	C	G	A	G	T	T	G	T	T	T	T	T	C	A	T	G	A	G	G	C	A	A	C	A	C	T
CMW 10214 <i>C. moniliformopsis</i>	G	C	A	A	A	G	A	G	G	T	C	G	A	G	T	T	G	T	T	T	T	T	C	A	T	G	A	G	G	C	A	A	C	A	C	T
CMW 3276 <i>C. virescens</i>	G	T	T	G	T	T	G	G	A	T	C	T	G	A	G	T	C	T	T	G	T	G	T	C	C	C	C	T	A	C	C	A	C	-	C	T

	1120										1130										1140										1150									
CMW 13011 <i>C. tribiliformis</i>	G	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	C	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 13012 <i>C. tribiliformis</i>	G	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	C	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 13013 <i>C. tribiliformis</i>	G	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	C	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 13015 <i>C. tribiliformis</i>	G	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	C	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 11048 <i>C. calidophila</i>	A	C	C	C	-	C	G	C	C	C	G	G	C	G	G	G	T	A	G	T	G	T	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 3800 <i>C. calidophila</i>	A	C	C	C	-	C	G	C	C	C	G	G	C	G	G	G	T	A	G	T	G	T	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 8242 <i>C. bhutanensis</i>	A	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	G	T	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 8217 <i>C. bhutanensis</i>	A	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	G	T	T	G	T	G	T	T	G	T	G	A	A	A	A	A				
CMW 9590 <i>C. moniliformis</i>	A	C	C	C	A	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	A	T	G	A	A	A	A	A				
CMW 10134 <i>C. moniliformis</i>	A	C	C	C	A	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	A	T	G	A	A	A	A	A				
CMW 4114 <i>C. moniliformis</i>	A	C	C	C	A	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	A	T	G	A	A	A	A	A				
CMW 9990 <i>C. moniliformis</i>	A	C	C	C	A	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	A	T	G	A	A	A	A	A				
CMW 8240 <i>C. moniliformis</i>	A	C	C	C	A	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	A	T	G	A	A	A	A	A				
CMW 8379 <i>C. moniliformis</i>	A	C	C	C	A	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	A	T	G	A	A	A	A	A				
CMW 9986 <i>C. moniliformopsis</i>	G	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	G	T	G	G	A	A	A	A				
CMW 10214 <i>C. moniliformopsis</i>	G	C	C	C	-	C	G	C	C	T	G	G	C	G	G	G	T	A	G	T	T	T	T	G	T	G	T	T	G	T	G	G	A	A	A	A				
CMW 3276 <i>C. virescens</i>	G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	C	A	G	C	C	A	T	C	T	C	A	A	T	-	-	A	A	A				

	1160										1170										1180															
CMW 13011 <i>C. tribiliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	G	C	A	C	-	A	C	A	A	G	G
CMW 13012 <i>C. tribiliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	G	C	A	C	-	A	C	A	A	G	G
CMW 13013 <i>C. tribiliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	G	C	A	C	-	A	C	A	A	G	G
CMW 13015 <i>C. tribiliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	G	C	A	C	-	A	C	A	A	G	G
CMW 11048 <i>C. calidophila</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	-	-	C	A	T	A	A	C	A	A	G	G
CMW 3800 <i>C. calidophila</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	-	-	C	A	T	A	A	C	A	A	G	G
CMW 8242 <i>C. bhutanensis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	A	G	G	A	A	G	A	C	A	T	-	A	C	A	A	G	G
CMW 8217 <i>C. bhutanensis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	A	G	G	A	A	G	A	C	A	T	-	A	C	A	A	G	G
CMW 9590 <i>C. moniliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	T	C	A	T	-	A	C	A	A	G	G
CMW 10134 <i>C. moniliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	T	C	A	T	-	A	C	A	A	G	G
CMW 4114 <i>C. moniliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	T	C	A	T	-	A	C	A	A	G	G
CMW 9990 <i>C. moniliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	T	C	A	T	-	A	C	A	A	G	G
CMW 8240 <i>C. moniliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	T	C	A	T	-	A	C	A	A	G	G
CMW 8379 <i>C. moniliformis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	T	C	A	T	-	A	C	A	A	G	G
CMW 9986 <i>C. moniliformopsis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	T	C	A	T	-	A	C	A	A	G	G
CMW 10214 <i>C. moniliformopsis</i>	A	T	T	C	T	A	C	T	C	T	T	T	C	C	T	C	T	T	T	G	G	G	A	A	G	C	T	A	T	-	A	C	A	A	G	G
CMW 3276 <i>C. virescens</i>	A	T	C	C	C	A	-	T	G	C	T	T	G	-	-	-	T	T	-	-	C	G	A	A	C	C	C	C	-	A	C	T	A	G	C	C

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	1190										1200										1210										1220									
CMW 13011 <i>C. tribiliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	C	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 13012 <i>C. tribiliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	C	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 13013 <i>C. tribiliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	C	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 13015 <i>C. tribiliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	A	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 11048 <i>C. calidophila</i>	G	T	A	T	A	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	A	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 3800 <i>C. calidophila</i>	G	T	A	T	A	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	A	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 8242 <i>C. bhutanensis</i>	G	T	A	T	A	A	T	T	A	C	C	C	C	G	C	T	G	T	C	T	T	G	T	A	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 8217 <i>C. bhutanensis</i>	G	T	A	T	A	A	T	T	A	C	C	C	C	G	C	T	G	T	C	T	T	G	T	A	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 9590 <i>C. moniliformis</i>	G	T	A	T	A	A	T	T	A	C	C	C	C	G	C	T	A	T	T	T	T	G	C	C	C	C	C	T	G	T	A	C	A	A	A	G				
CMW 10134 <i>C. moniliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	A	T	T	T	T	G	C	C	C	C	C	T	G	T	A	C	A	A	A	G				
CMW 4114 <i>C. moniliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	A	T	T	T	T	G	C	C	C	C	C	T	G	T	A	C	A	A	A	G				
CMW 9990 <i>C. moniliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	A	T	T	T	T	G	C	C	C	C	C	T	G	T	A	C	A	A	A	G				
CMW 8240 <i>C. moniliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	C	C	C	C	C	T	G	T	A	C	A	A	A	G				
CMW 8379 <i>C. moniliformis</i>	G	T	A	C	A	A	T	T	A	C	C	C	C	G	C	T	A	T	T	T	T	G	C	C	C	C	C	T	G	T	A	C	A	A	A	G				
CMW 9986 <i>C. moniliformopsis</i>	G	T	G	T	T	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	C	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 10214 <i>C. moniliformopsis</i>	G	T	G	T	T	A	T	T	A	C	C	C	C	G	C	T	G	T	T	T	T	G	T	C	C	C	C	T	G	T	A	C	A	A	G	G				
CMW 3276 <i>C. virescens</i>	T	A	G	G	-	A	T	T	G	A	A	C	C	C	C	T	G	-	-	-	-	-	-	-	-	-	-	G	C	A	C	-	-	-	-	-				

This dissertation represents a study on *Ceratocystis* spp. with hat-shaped ascospores. Previously only six species of *Ceratocystis* with this spore form were known. These include *C. fimbriata*, *C. pirilliformis*, *C. albofundus*, *C. moniliformis*, *C. moniliformopsis* and *C. acericola*. In this study, we have discovered and tentatively described three new species with hat-shaped ascospores. One of these group with the larger *C. fimbriata* clade, while the other two reside within the larger *C. coeruleascens* clade.

Chapter one provides a concise summary of the literature pertaining to the genus *Ceratocystis*. The intention of the chapter is to introduce readers to this important genus of plant pathogens and to provide a background regarding their taxonomy, ecology, biochemistry and variation in species. Emphasis is placed on the distinction of *Ceratocystis* from *Ophiostoma*, as well as on those *Ceratocystis* spp. with hat-shaped ascospores that negatively impact upon plantation forestry species. This chapter shows how *Ceratocystis* spp. associated with hardwood species in commercial forestry plantations have increased in number and it provides the background for research presented in the following five chapters.

In the second chapter of this dissertation, a new species of *Ceratocystis* was discovered amongst isolates from the Himalayan mountain range of Bhutan. This fungus, in association with the bark beetle *Ips schmutzenhoferi*, is responsible for large-scale deaths of Himalayan spruce trees in Bhutan. The fungus is morphologically very similar to *C. moniliformis* and *C. moniliformopsis*, but differences in culture morphology, survival at different incubation temperatures and DNA sequence data based on three different gene regions supported the fact that this is a unique species. The fungus has thus been tentatively described as *Ceratocystis bhutanensis* *prov. nom.*

In chapter 3, I consider isolates of a *Ceratocystis* sp. recently discovered associated with dying clove trees in Northern Sulawesi, Indonesia. The fungus was found at a very high level of incidence, but was at first identified as *C. fimbriata*, based on morphological characteristics. Differences were observed in cultures of this fungus when they were compared with *C. fimbriata* especially in terms of colony colour and growth at different

temperatures. Morphological differences were also observed when the clove fungus was compared with *C. fimbriata* isolates. When three different DNA gene regions were sequenced and compared, it was clear that this fungus represents a new species. The fungus is, therefore, tentatively described as *Ceratocystis polychroma* prov. nom. in this dissertation.

Ceratocystis polychroma prov. nom. isolates obtained from cloves in Sulawesi displayed three distinctly different culture morphologies. In Chapter 4 of this dissertation we, used DNA sequence data and microsatellite markers to consider whether these differences could be observed at the molecular level. Comparisons of sequence data for the ITS region gave no distinction between any of the morphological groups. A total of 50 isolates were studied using microsatellites markers developed for *C. fimbriata*. No distinction could be obtained between isolates representing the three different culture morphological groups. The 50 isolates were subsequently treated as one population in further analyses. With the aid of the microsatellite markers, it was shown that that this population probably originated from Sulawesi and that it benefits from sexual outcrossing.

In chapter five of this dissertation, a study was undertaken to consider the taxonomic status of *C. moniliformis*. Considerable variation has been noted in different descriptions of this species. It also has a very wide host and geographic distribution raising speculation that *C. moniliformis* represents a species complex rather than a single taxon. Based on morphological and DNA sequence data from three gene regions, isolates from Sumatra were described as a new species, which we have tentatively named *C. tribiliformis* prov. nom. The other *C. moniliformis* isolates were all the same, despite the fact that they originated from a wide range of hosts and areas. The fungus correctly bearing the name *C. moniliformis*, *C. moniliformis sensu stricto*, therefore does not seem to represent a species complex. Species such as the closely related *C. tribiliformis* prov. nom., *C. bhutanensis* prov. nom., *C. omanensis* prov. nom. and *C. moniliformopsis* all belong to the larger *C. moniliformis sensu lato* group, and all have hat-shaped ascospores, conical spines on the ascomatal bases, disc-shaped bases to the ascomatal necks and are phylogenetically closely related to *C. moniliformis*.

Studies presented in this dissertation provide considerable new knowledge regarding various *Ceratocystis* spp. with hat-shaped ascospores. Three new species are described and I have also been able to show that *C. moniliformis sensu stricto* is monophyletic. Two of the species (*C.*

tribiliformis prov. nom. and *C. bhutanensis* nom. prov) group within the larger *C. coerulescens* clade while *C. polychroma* prov. nom. groups within the larger *C. fimbriata* clade. Studies in this dissertation have also improved our knowledge of the identity of several species previously incorrectly identified as either *C. moniliformis* or *C. fimbriata*. What has clearly emerged from this dissertation is the need for a monograph of *Ceratocystis* to include all new species and to thoroughly consider the population biology and ecology of all species