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Eucalypt diseases and their management in China

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Abstract Eucalypts were first introduced into China in 1890 and the first commercial eucalypt plantation was established in ZhanJiang, GuangDong province in 1954. Because natural ecosystems have been strictly protected from logging since 2000, eucalypt plantations in South China have been substantially expanded to meet the needs of a rapidly growing local economy. Approximately 3.6 million ha of eucalypt plantations have now been established and half of these represent clones of *Eucalyptus urophylla* x *E. grandis*, and *E. camaldulensis* x *E. grandis* hybrids. However, the sustainable development of the eucalypt plantations is under increasing threat due to pathogens and pests. The fact that there has been very limited work on eucalypt pathology in China compounds this fact. During the course of past five years, a programme known as the CFEPP (http://www.fabinet.up.ac.za/cfepp/index) focusing on eucalypt health problems in China has been developed, and a large number of eucalypt disease surveys have been conducted in areas such as GuangXi, GuangDong, HaiNan, FuJian and Yunnan. This work has resulted in the collection of over 2000 fungal strains many of which are well-known eucalypt pathogens. A total of 30 fungal species (eight of them new to science) residing in 11genera such as *Calonectria*, *Celoporthe, Chrysorporthe*, *Quambalaria* and *Teratosphaeria*, have been characterized based on comparisons of morphology and DNA sequence data. Both glass-house and field trials have been conducted to test the pathogenicity of the most important of these fungi on commercially used eucalypt clones. Results have shown that there are significant differences in the susceptibility of these clones to fungal isolates/species, indicating that selection of resistant material for commercial planting in the future can be achieved.

Keywords Plantation · Tree health · Forest pathogens · Southeast Asia

Introduction

Eucalypts represent a group of trees including more than 900 species, residing in the genera of *Eucalyptus*, *Corymbia* and *Angophora* (Brooker 2000; Keane et al. 2000; Nicolle 2006; Wang 2010). *Eucalyptus* and *Corymbia* species are best known due to the fact that they have been widely deployed in plantations for commercial purposes. In general, they grow rapidly, adapt well to a variety of environments, and many species/clones have been cultivated to meet a wide variety of needs such as pulp for paper, plywood, fuel wood, charcoal, ties for railroad tracks, poles, mining timber, furniture and material for building construction (Eldridge et al. 1997; Qi 2002), essential oils for perfumery and medicinal purposes, and bark for tannin production (Qi 2002).

Eucalypts are mainly endemic to Australia, with a few species such as *E. urophylla*, *E. deglupta*, *E. wetarensis*

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indigenous to Indonesia, Papua New Guinea and the Philippines (Keane et al. 2000; Wang 2010). Many eucalypt species/clones have been widely introduced into other parts of the world, especially in tropical and subtropical areas for plantation development. By 2009, over 20 million ha of eucalypt plantations had been established throughout the world (Iglesias-Trabad et al. 2009). The four countries with the largest areas of planted eucalypts are Brazil (21%), India (19%), China (13%), and Australia (5%) (Iglesias-Trabad et al. 2009).

Importance of eucalypts in China

Eucalypts were first introduced into China in 1890. They were often used as ornamental trees and planted in parks and villages in South China. In 1954, the first eucalypt plantation was established in Zhanjiang, Guangdong Province. Thus-far, more than 300 species have been introduced mainly from Australia, into the areas such as GuangDong, GuangXi, HaiNan, YunNan and FuJian Provinces. Of these, approximately ten are economically important species that have been widely planted (Table 1) (Qi 2002; Qi et al. 2006). These include species such as *E. grandis*, *E. urophylla*, *E. camaldulensis*, *E. dunnii*, *E. globulus*, *E. maidenii*, *E. saligna*, *E. tereticornis*, as well as their hybrids and clones (Qi 2002; Qi et al. 2006). This rapid development of eucalypt plantations was achieved mainly due to successful implementation of two Australia-China intergovernmental projects. One of these projects, which ran between 1981 and 1989, led to the introduction and testing of 40 eucalypt species. The second project was between 1984 and 1992, with additional 70 species introduced for testing in the country (Qi 2002).

Chinese natural forests have been strictly protected from logging since 2000, especially for environmental reasons. However, with the rapid growth of the national economy, which was ranked second in the world in 2010, there is a continuously increasing need for pulp, paper and wood products. It has thus been estimated by the Chinese State Forestry Administration that by 2015, approximately 330–340 million m^3 will be required to meet local needs and of this, 190 million m^3 could be produced locally. This will require extensive and productive eucalypt plantations, which already represent the most important and fastest-growing trees in South China. Current data suggest that a total of 3.6 million ha of eucalypt plantations have already been established in South China and that these represent a relatively small number of clones. Eucalypts provide around 20 million m^3 of wood annually, thus contributing to 18% of national wood demand using 3% of forest land.

Establishment of CFEPP

The world-wide trend is that sustainable development of eucalypt plantations is increasingly threatened by pests and pathogens (Wingfield et al. 2001, 2008, 2011). In China, commercial eucalypt plantation forestry began only half century ago and is thus a relatively new industry. Local eucalypt plantations were relatively free of their natural enemies and were established without major pest and pathogen problems in the past. However, with extensive development of eucalypt plantations and large-scale deployment of very limited numbers of clones (less than 10) in the past twenty years, pests and pathogens have appeared and begun to cause serious damage,

Table 1 Nine most popular eucalypt species planted in China (Qi 2002; Qi et al. 2006)

Species	Origin	Distribution (Province/Region)
Eucalyptus urophylla	Archipelago, Eastern Indonesia	GuangDong, GuangXi and HaiNan, etc.
E. grandis	Eastern Australia	SiChuan, GuangDong and GuangXi, etc.
E. camaldulensis	Australia	FuJian, GuangDong, GuangXi, HuNan, ShangHai, SiChuan, YunNan and ZheJiang
E. globulus	New South Wales and Victoria, Australia	GuangXi, GuiZhou, JiangSu, JiangXi, SiChuan and YunNan
E. maidenii	New South Wales and Victoria, Australia	GuangDong, GuangXi and YunNan
E. tereticornis	Australia	FuJian, GuangDong, GuangXi, JiangXi, SiChuan, YunNan and ZheJiang
E. dunnii	Eastern Queensland and New South Wales of Australia	FuJian, HuNan and JiangXi
E. saligna	New South Wales and Queensland, Australia	GuangDong, GuangXi, SiChuan and YunNan
Corymbia citriodora	Queensland, Australia	FuJian, GuangDong, GuangXi, HuNan, JiangXi, SiChuan, YunNan and ZheJiang, etc.

resulting in significant economic losses to the industry and to farmers. Recent data have indicated that the annual loss due to pests and pathogens is over $70 million. It is, therefore, of great concern that there is very limited expertise to deal with eucalypt pests and pathogens in China.

The Forestry and Agricultural Biotechnology Institute (FABI; http://www.fabinet.up.ac.za/) represents one of the world's largest teams investigating pest and pathogen problems affecting plantation-grown forest trees, particularly those in the tropics, and is highly recognized internationally. The China Eucalypt Research Centre (CERC; http://www.chinaeuc.com) is the primary organisation working on eucalypts in China, and serves as the headquarters of China Eucalypt Society and China Eucalypt Breeding Alliance. During the period of 2003–2006, through exchange visits as well as via China-South Africa inter-governmental projects, FABI and CERC developed close research collaboration that led to the establishment of the CERC-FABI Eucalypt Protection Programme (CFEPP; http://www.fabinet.up.ac.za/cfepp). This Programme, in existence since 2006 provides a platform linked to major pulp and paper companies such as Stora_Enso and Asian Paper and Pulp Company (APP) to ensure the sustainable development of eucalypt plantations in China. This is achieved through research on the major pest and disease problems, monitoring of the health status of eucalypt plantations in China and through the provision of advice regarding pest and disease management. Furthermore, there has been a substantial focus on human capacity development with a growing number of students being trained in the field of forest protection.

Disease surveys and pathogen characterisation

During the course of the last five years, many disease surveys have been conducted in major eucalypt-growing areas including those in the provinces of Guangxi, Guangdong, Hainan, Yunnan, and Fujian in South China (Zhou et al. 2008; Chen et al. 2010). Samples including leaves, twigs, stems and roots showing symptoms of disease including cankers, rot disease, leaf spots and wilt were collected (Zhou et al. 2008) (Fig. 1). Likewise, soil samples were collected to consider the presence of pathogens and especially *Calonectria* species that are known to be important on *Eucalyptus* in China.

Isolation was conducted directly from diseased tissue. Where fruiting structures were present, spore masses were collected using a sterile needle under a dissection microscope and transferred to 2% malt extract agar (MEA) (20 g malt extract, 20 g agar, 1 L water). Soil samples were investigated for the presence of *Calonectria* species using the techniques described by Crous (2002).

Cultures were purified from preliminary isolations and single-spore cultures obtained for characterisation. A combination of morphology and multi-gene DNA sequence comparisons were used to confirm the identities of the isolates. Where necessary for identification based on the biological species concept, mating studies were conducted. Selected isolates of putative pathogens were also screened for pathogenictiy both in green house and field trials on commonly used eucalypt clones.

Pathogens and diseases

Disease surveys and subsequent studies to identify pathogens and to test their pathogenicity during the past 5 years and as part of the CFEPP, represent the most comprehensive investigation ever to have been undertaken on eucalypt diseases in China. During this period, more than 2000 isolates were obtained and cultures stored, and these represent 30 different fungal taxa with some connection to eucalypt disease. These also include six well-recognized fungal pathogens of eucalypts that were characterized using comparisons of morphology and DNA sequence data. They reside in the genera *Calonectria* (Lombard et al. 2010; Chen et al. 2011c), *Celoporthe* (Chen et al. 2011b), *Chrysoporthe* (Gryzenhout et al. 2009; Chen et al. 2010), *Fusicoccum* (Chen et al. 2011d), *Lasiodiplodia* (Chen et al. 2011d), *Neofusicoccum* (Chen et al. 2011d), *Quambalaria* (Zhou et al. 2007) and *Teratosphaeria* (Chen et al. 2011a). During the course of these investigations, eight new fungal taxa were discovered and have been or are in the process of being described (Lombard et al. 2010; Chen et al. 2011b, c, d). This has tremendously enriched our understanding and knowledge of eucalypt diseases and their causal agents (Table 2) in China.

Isolates of putative pathogens discovered in the disease surveys were selected for pathogenicity trials on different *Eucalyptus* genotypes in both glass house and field. The results made it possible to recognise the most important pathogens of eucalypts in China and these included fungi that were not previously known as pathogens. Furthermore, it was possible to show that there are significant differences in terms of variation in susceptibility of eucalypt genotypes to many pathogens tested (Chen et al. 2010, 2011a, b, c). For example, *Chrysoporthe deuterocubensis* (Van Der Merwe et al. 2010) caused significantly different lesions on seven tested eucalypt genotypes (Chen et al. 2010). Potential disease-resistant clones have thus been identified and these will be deployed in areas where substantial disease pressure exists.

Fig. 1 Eucalypt disease symptoms in China. (1) Stem canker caused by species within the Botryosphaeriaceae; (2) Lesion on the stems of a *Eucalyptus* sp. in China, 6 weeks after inoculation with *Lasiodiplodia theobromae*; (3) *Calonectria* spp. causing severe leaf blight in plantations; (4) Leaf blight and death of *Eucalyptus* seedlings, 6 weeks after inoculation with *Calonectria* spp.; (5) Bacterial wilt caused by *Ralstonia solanacearum*; (6) White bacterial masses flowing from freshly diseased tissue; (7) Coniothyrium canker caused by *Teratosphaeria zuluensis* on *E. grandis*; (8) Cryphonectria canker caused by *Chrysoporthe deuterocubensis* on *Syzygium cumini*

Future prospects

The demand for pulp, paper and fibre in China will obviously continue to increase to meet the needs of economic development and to comply with national strategies. There is no doubt that eucalypt plantations are a crucial source of wood and fibre in China and the need for this resource will grow in the future. There is very limited land available for the development of eucalypt plantation and thus-far, yields of eucalypt wood in South China have been relatively low. To improve this situation, it will be necessary to improve the productivity of clones and especially to develop cold-tolerant clones for planting in areas further north than is currently possible. In addition, it

Table 2 Eucalypt diseases and their causal agents recorded in mainland China

Pathogen/causal agent	Host	Date recorded	Reference to first record
Ralstonia solanacearum	*Eucalyptus grandis*, *E. saligna*	1982	Cao 1982
Chrysoporthe deuterocubensis	*Eucalyptus* sp.	1985	Sharma et al. 1985
Teratosphaeria suttonii	*Eucalyptus* spp.	1997	Crous and Wingfield 1997
T. destructans	*E. urophylla*, *Eucalyptus* spp.	2006	Burgess et al. 2006
T. zuluensis	*E. urophylla*	2006	Cortinas et al. 2006
Mycosphaerella marksii	*Eucalyptus* sp.	2007	Burgess et al. 2007
M. crystallina	*E. urophylla*	""	""
M. yunnanensis	""	""	""
Quambalaria pitereka	*Corymbia citriodora*	2007	Zhou et al. 2007
Botryosphaeria spp.	*Eucalyptus* spp.	2008	Zhou et al. 2008
Calonectria (*Cylindrocladium*) spp.	""	""	""
Ceratocystis sp.	""	""	""
Mycosphaerella spp.	""	""	""
Pilidiella sp.	Eucalyptus sp.	""	""
Neofusicoccum parvum	""	2009	Slippers et al. 2009
N. ribis	""	""	""
N. mangiferum	""	""	""
Calonectria cerciana	*E. urophylla* × *E. grandis* cutting	2010	Lombard et al. 2010
Ca. pauciramosa	""	""	""
Ca. pseudoreteaudii	""	""	""
Ophiostoma tsosi	*Eucalyptus* wood chips	2011	Grobbelaar et al. 2011
Ca. crousiana	*E. grandis*	2011	Chen et al. 2011c
Ca. fujianensis	""	""	""
Ca. pseudocolhounii	*E. dunnii*	""	""
Fusicoccum fabicercianum	*E. grandis hybrid*, *E. Urophylla x tereticornia*, *Eucalyptus* sp.	2011	Chen et al. 2011d
Lasiodiplodia theobromae	*Eucalyptus* sp.	""	""
L. pseudotheobromae	""	""	""
Celoporthe sp1	""	2011	Chen et al. 2011b
Celoporthe sp2	*Eucalyptus* EC48 clone	""	""

will be necessary to breed and select eucalypt clones that are resistant to the ravages of disease such as those that have been highlighted in this paper. In this regard, avoidance of disease by planting resistant species and breeding and selection for disease- tolerant eucalypt clones has been highly successful elsewhere in the world (Wingfield 2003). Following the same approach, it should be possible to reduce the impact of pests and diseases of eucalypts in China in the future.

The number of disease and pest problems on eucalypt plantations in China will continue to grow. This has been true elsewhere in the world (Wingfield et al. 2001, 2008, 2011; Old et al. 2003; Wingfield 2003) and arises from the movement of forestry material in the form of seed, planting stock, timber and wood products between regions, countries and continents. In addition, there is growing evidence that new eucalypt diseases are arising from host shifts (Slippers et al. 2005, 2009) of fungi that occur on native Myrtaceae and that have adapted the capacity to infect *Eucalyptus* (Wingfield et al. 2010). Although the origin of many pathogens treated in this paper is not known, it is probable that many if not most of them are native to China. For example *Chrysoporthe deuterocubenis* is known to occur on native Myrtaceae in Asia and has almost certainly undergone a host shift to infect eucalypts in China (Chen et al. 2010). The same is probably true for *Teratosphaeria zuluensis* (Andjic et al. 2007; Crous et al. 2009; Cortinas et al. 2010). In addition to these more host-specific pathogens, wide host-range pathogens such as *Calonectria* spp. appear to be very common in China and these are causing serious disease problems on eucalypts (Lombard et al. 2010; Chen et al. 2011c).

A vivid example of a eucalypt pathogen that has the capacity to impart serious damage in China is rust caused by *Puccinia psidii*. This pathogen is native to South and

Central America and underwent a host shift to infect *Eucalyptus* and other Myrtaceae in that part of the world (Coutinho et al. 1998; Glen et al. 2007). *Eucalyptus* rust has been feared as a pathogen in areas of the world with large numbers of native Myrtaceae such as Australia, and also in countries that cultivate eucalypts in plantations. The recent appearance of *P. psidii* in Australia (Glen et al. 2007; Langrell et al. 2008) and its rapid spread in native ecosystems is of great concern. This epidemic also presents a "bridgehead" for the pathogen to reach new areas including China that is geographically relatively close. It seems highly likely that it will invade countries of South East Asia in the relatively near future.

Diseases present a huge challenge for *Eucalyptus* plantation development in China. This is a challenge that will grow and it will need to be faced with substantial resources. The first line of defence must be to build up a strong base of human capacity to deal with disease problems and to assist plantation managers with responsible and evidence-based advice. This team of pathologists and entomologists will likewise need to work in close collaboration with geneticists to provide a continuous source of disease tolerant planting stock.

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