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REVIEW ARTICLE

Chilli anthracnose (*Colletotrichum* spp.) disease and its management approach

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Abstract

Chilli is a widely consumed crop throughout the world. However, chilli anthracnose is a major constraint in chilli production leading to huge economic losses worldwide. *Colletotrichum* is a large genus of Ascomycete fungi, containing species that cause anthracnose diseases on a wide range of crops of economic value. This review is aimed at critically and accurately examining the taxonomic identification of *Colletotrichum* species by morphological and molecular approaches as well as assessing their management options. The use of appropriate integrated management practices, such as cultural, mechanical, chemical, and biological control, are important in chilli anthracnose disease prevention and control. Emphasis is laid on the use of biological control because it is cost effective and eco-friendly, and is an appropriate approach for disease management. The use of resistant cultivars is the cheapest, easiest, safest, and most effective means of controlling crop diseases. But, since no resistant cultivars of chilli have been developed and commercialized, it is very important to develop biological management strategies. Further studies leading to integrated disease management strategies need to be carried out.

Keywords: anthracnose disease, *Colletotrichum* species, management strategy

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Introduction

Based on perceived scientific and economic importance, it was recently voted that *Colletotrichum* was the eighth most important group of plant pathogenic fungi in the world (Dean et al., 2012). Many researchers have reported that *Colletotrichum* causes anthracnose disease and postharvest decay on a wide range of tropical, subtropical, and temperate fruits, crops and ornamental plants (Bailey and Jeger 1992; Bernstein et al., 1995; Freeman et al., 1996; Lahoz et al., 2009; Lima et al., 2011; Damm et al., 2012). Among these hosts, chilli pepper (*Capsicum* spp.), an important economic crop worldwide (Poulos, 1992), is severely affected by chilli anthracnose which can result in yield losses of up to 50% (Pakdeevaraporn et al., 2005). Chilli is a very important vegetable because of its massive consumption worldwide. Not only is it used in many cuisines but it is also found to have many medicinal properties. In addition, chilli can reduce the risk of cancer by preventing carcinogens from binding to DNA and reduce calorie intake by increasing thermogenesis

(Lakshmi et al., 2014). The chilli anthracnose disease caused by *Colletotrichum* species drastically reduces the quality and yield of chilli fruits resulting in low returns to farmers. In Korea, it results in a reduction of approximately 13% of marketable yield (Yoon et al., 2004). Moreover, in Korea, annual chilli production revenue is estimated to be US $1.4 billion and the annual damage by this disease has been valued at more than US$100 million (Kim et al., 2008).

Typical anthracnose symptoms on chilli fruits include sunken necrotic tissues, with concentric rings of acervuli and fused lesions. Conidial masses may occur under severe conditions. Several species of *Colletotrichum* etiologically associated with anthracnose diseases in chilli include *C. acutatum*, *C. coccodes*, *C. dematium,* and *C. gloeosporioides* in Korea (Park and Kim, 1992). According to Kim et al. (2004), different species infect chilli plants at different growth stages. Leaves and stems are damaged by *C. coccodes* and *C. dematium* whereas *C. acutatum* and *C. gloeosporioides* infect chilli fruits in Korea. *Colletotrichum capsici* is found to be prevalent in red chilli fruits whereas *C. acutatum* and *C. gloeosporioides* cause infections both in young and mature chilli fruits (Hong and Hwang, 1998; Kim et al., 1999; Kim et al., 2004; Park et al., 1990; Than et al., 2008). Among these species, *C. gloeosporioides* and *C. acutatum* are the most destructive and widely distributed (Sarath Babu et al., 2011; Voorrips et al., 2004).

Anthracnose Disease

Anthracnose

Anthracnose is the common name for plant diseases characterized by very dark, sunken lesions, containing spores (Isaac, 1992). It directly reduces the quality and quantity of the harvested yield. Disease infection and disease progress of chilli anthracnose can be promoted at a temperature of approximately 27°C with 80% relative humidity and a soil pH of 5-6 (Roberts et al., 2001). Several losses may occur in rainy weather because the spores of *Colletotrichum* are splashed or washed onto other fresh fruits resulting in more infection (Roberts et al., 2001). *Colletotrichum* species are the most important pathogens to cause latent infections (Jeffries et al., 1990). Typical fruit symptoms are circular or angular sunken lesions and concentric rings of acervuli that are often wet and produce pink to orange conidial masses. Under severe disease conditions, lesions may coalesce. Conidial masses may also occur scattered or in concentric rings on the lesions. Based on the report by Kim et al. (2008), the major pathogen causing chilli anthracnose in Korea may be *C. acutatum* rather than *C. gloeosporioides*. Typical fruit symptoms and colony types of *C. acutatum* are shown in Fig. 1.

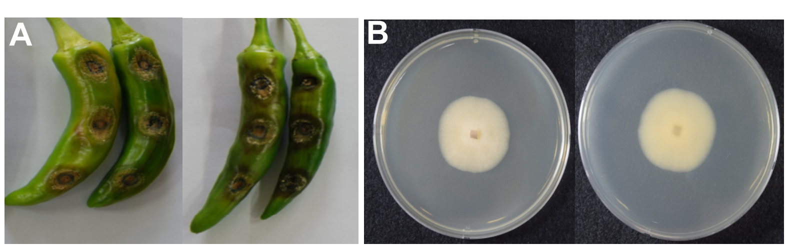

Fig. 1. Typical fruit symptoms and colony types of *Colletotrichum acutatum*. (A) Sunken necrotic lesion on chilli fruit, (B) White to orange colonies of *C. acutatum*.

Colletotrichum

Colletotrichum is one of the most important phytopathogens worldwide causing the economically important disease *anthracnose* in a wide range of hosts (Bailey and Jeger, 1992). The causal agent of chilli anthracnose disease is *Colletotrichum* which belongs to Kingdom-Fungi, Phylum-Ascomycota, Class-Sordariomycetes, Order-Phyllachorales, and Family-Phyllachoraceae. Causal agents of chilli anthracnose in different countries are tabulated in Table 1 (Than et al., 2008). Kim et al. (2004) reported that different species of *Colletotrichum* affect different organs of the chilli plant; for examples, *C. acutatum* and *C. gloeosporioides* infect chilli fruits at all developmental stages, but not usually the leaves or stems, which are mostly damaged by *C. coccodes* and *C. dematium*. Leaf anthracnose of chilli seedlings caused by *C. coccodes* was first reported in chilli growing in a field in Chungnam Province of Korea in 1988 (Hong and Hwang, 1988).

Table 1. Geographic distribution of *Colletotrichum* species on Chilli.

Country[y]	*Colletotrichum* species	References
Australia	*C. siamense, C. simmondsii, C. queenslandicum, C. truncatum and C. cairnsense*	De Silva et al., 2016
India	*C. capsici, C.cocodes,C. fruticola and C. siamense*	Paul and Behl, 1990; Sharman and Shenoy; 2014; Sharma et al., 2011
Indonesia	*C. acutatum, C. capsici, C. gloeosporioides*	Voorrips et al., 2004
South Korea	*C. acutatum, C. gloeosporioides, C. coccodes, C. dematium*	Park and Kim,1992
Myanmar	*Gloeosporium poperatum* E. and E., C. *nigrum* E. and Hals, *C. capsici*	Dastur, 1920; CPC 2007[z]
Papua New Guinea	C. capsici, C. gloeosporioides	Pearson et al.,1984
New Zeland	C. coccodes	Johnston and Jones, 1997
Taiwan	C. acutatum, C. capsici, C. gloeosporioides	Manandhar et al., 1995
Thailand	C.acutatum, C.capsici, C,gloeosporioides	Than et al., 2008
Vietnam	C. acutatum, C. capsici, C. gloeosporioides, C. nigrum	Don et al., 2007

[y]Asia-Pacific Countries, [z]CPC; Crop Protection Compendium.

Most *Colletotrichum* species are seed borne and may survive in soil or on infected crop debris. Conidia may be spread by water splash dispersal whereas transmission of ascospores can occur through the air (Nicholson et al., 1980). They are capable of growing in and on seeds as acervuli and micro-sclerotia (Pernezny et al., 2003). *Colletotrichum* species naturally produce micro-sclerotia to allow dormancy in the soil during the winter or when subjected to stressful conditions, and these micro-sclerotia can survive for many years (Pring et al., 1955). Once the pathogen penetrates the host plant, establishment of the fungus in plant tissue is aided by host induced virulence effectors. *Colletotrichum* species produce a series of specialized infection structures such as germ tubes, appressoria, intracellular hyphae, and secondary necrotrophic hyphae (Perfect et al., 1999).

Characterization of Colletotrichum Species

Morphological Characterization

For effective disease management, accurate identification of *Colletotrichum* species is essential. Classically, identification and characterization of *Colletotrichum* species have primarily relied on morphological characters such as colony color, size and shape of conidia, optimal temperature for growth, growth rate, presence or absence of setae, and existence of the teleomorph, *Glomerella* (Freeman et al., 1998). Conidial morphology has been traditionally emphasized over other taxonomic criteria, although conidia of *Colletotrichum* are potentially variable. Several researchers reported that the growth rate of *C. gloeosporioides* was higher than that of *C. acutatum* (Agostini et al., 1992; Liyanage et al., 1992). Adaskveg and Hartin (1997) reported that, considering mycelial growth responses to temperature, *C. acutatum* from strawberry, almond, and peach grew well at 25°C while *C. gloeosporioides* from citrus and papaya grew well at 30°C. Table 2 shows the morphological data of *Colletotrichum* species (Sutton, 1992).

Table 2. Morphological data for *Colletotrichum* species.

Species	Colony Color	Conidia			Aspersoria			Sclerotia	Setae
		Length (μm)	Width (μm)	Shape	Length (μm)	Width (μm)	Shape		
C. acutatum	White to pinkish gray or orange color colony with slight mycelium	8.5-10	4.5-6	Fusiform, medianly constricted	8.5-10	4.5-6	Clavate or irregular	Present	Absent
C. capsici	White to gray color with dark green centre and cottony mycelium	18-23	3.5-4	Falcate, fusiform apices acute	9-14	6.5-11.5	Clavate to circular	Abundant	Absent
C. coccodes	White mycelia	16-22	3-4	Fusiform medianly constricted	11-16.5	6-9.5	Long clavate irregular	Present	Abundant
C. dematium	White to grey or dark brown	19.5-24	2-2.5	Falcate, fusiform apices acute	8-11.5	6.5-8	Clavate to circular	Abundant	Abundant
C. gloeosporioides	Varied	9-24	3-4.5	Straight, obtuse at apex	6-20	4.12	Clavate to irregular	Varied	Varied

Molecular Characterization

One of the most serious problems in chilli anthracnose is that two pathogens, *C. acutatum* and *C. gloeosporioides* cannot easily be differentiated based on morphological and cultural characteristics due to environment-induced changes in morphological characteristics. Therefore, to overcome this problem, DNA sequence analyses have been used to characterize and analyze the taxonomic complexity of *Colletotrichum*. Canon et al. (2000) stated that data derived from DNA analyses is the most reliable framework for classifying *Colletotrichum* as DNA is not directly influenced by environmental factors. In particular, sequence analysis of the internal transcribed spacer (ITS) regions lying between the 18S and 5.8S genes and the 5.8S and 28S genes, has proved very useful in studying phylogenetic relationships among *Colletotrichum* species (Sreenivasaprasad et al., 1996; 1996; Moriwaki et al., 2002; Photita et al., 2005). Sequence analysis of protein coding genes such as partial β-tubulin gene and introns from two genes (glutamine synthetase and glyceraldehyde-3-phosphate dehydrogenase) were also useful in resolving the phylogenetic relationships among *C. acutatum* species (Sreenivasaprasad and Talhinhas, 2005; Guerber et al., 2003). Although ITS sequences do not separate the *C. gloeosporioides* complex, some single genes or combination of genes, glutamine synthetase, and glyceraldehydes-3-phosphate dehydrogenase (GAPDH), can be used to differentiate *Colletotrichum* species (Weir et al., 2012). Isolates of *C. acutatum* were phylogenetically separated from A1 to A4 subgroups based on sequences in partial β-tubulin 2 (exons 3-6) (Talhinhas et al., 2002). According to Canon et al. (2000), an integrated approach, where molecular diagnostic tools are applied along with morphological characterization, is a more accurate and reliable approach for studying *Colletotrichum* species.

Pathogenic Variability

When any of the progeny exhibits a characteristic that is different from those present in the ancestral individuals, this individual is called a variant (Agrios, 2005). Compatibility of plant-pathogen interactions is often governed by the gene-for-gene model in many pathosystems (Flor, 1971). Some pathogen populations are known to be pathogenically diverse and the diversity seems to be due to continuous generation of novel pathogenic variations (Taylor and Ford, 2007). A genotype with partial resistance would result in lower levels of infection which eventually would decrease the amount of inoculum in the field and limit the potential of epidemics.

Several studies (AVRDC, 1999; Yoon et al., 2004) have screened *C. acutatum*, which is a very virulent species (Than et al., 2008) against chilli genotypes and found that *Capsicum baccatum* genotype ‘PBC 80’ is a genetic resource pool for resistance to anthracnose. However, another genotype of *C. baccatum*, ‘PBC81’ showed high susceptibility to some *C. acutatum* isolates. In contrast to *C. baccatum*, the susceptibility of the cultivar *Capsicum annuum* has been reported in several studies (Mongkolporn et al., 2004; Park, 2007). Moreover, *Capsicum chinense* ‘PBC932’ has been reported as a resistant variety to *C. capsici* (AVRDC, 2003). However, to date, there has not been any strong resistance found in *C. annuum*, which is the only species grown worldwide (Park, 2007).

Disease Management

There are various methods of controlling plant disease. As no single strategy is found to be very effective in controlling chilli anthracnose disease, Agrios (2005) recommended an integrated disease management approach. Effective approaches for disease management usually involve the combined use of intrinsic resistance along with cultural, mechanical, biological, and chemical control (Wharton and Dieguez-Uribeondo, 2004).

Using resistant varieties may eliminate losses from diseases as well as chemical and mechanical expenses of diseases control (Agrios, 2005). The use of shorter ripening period cultivars may allow fruits to be harvested earlier in order to prevent infection by the fungus. Crop rotation should be done at least 2 years with crops that are not *Solanaceous* plants. As the pathogen is capable of remaining in the soil and in plant debris, soil must be deeply ploughed to completely bury the crop residues containing the pathogens (Agrios, 2005). Among disease control management approaches, the use of resistant cultivars is the cheapest, easiest, safest, and most effective means of controlling diseases.

Chemical Control

Use of chemicals is a widely used disease control strategy and a practical method to control anthracnose disease. However, fungicide resistance often arises quickly, if a single compound is relied upon too heavily (Staub, 1999). A fungicide widely recommended for anthracnose management in chilli is manganese ethylene bis dithiocarbamate

(Maneb) (Smith, 2000). Chakravarthy (1975) recommended that soaking of chilli seeds for 12 hours in 0.2% thiram is best way to control *Colletotrichum* species.

The strobilurin fungicides azoxytrobin (Quadris), trifloxystrobin (Flint), and pyraclostrobin (Cabrio) have recently been recommended for the control of chilli anthracnose (reviewed by Than et al., 2008). Moreover, various fungicides have been found to be effective, including 0.2% mancozeb, 0.1% ziram, Blitox 50, 0.1% Bavistin and 0.5% or 1% Bordeaux mixture; benlate and Delsene M are used as seed dressings (CPC, 2007). However, there are numerous undesirable effects of using chemicals such as on farmers' income, the toxic effects of chemicals on farmers, and other environmental concerns, particularly in developing countries (Voorrips et al., 2004).

Biological control

To overcome the negative effect of chemical usage, use of plant extracts and biocontrol agents to control infection have become a solution. Complete inhibition of fungal growth and spore germination were achieved with the use of 3% garlic bulb extract concentration (Singh, 1997). Crude extracts from different parts of Sweet flag, Palmorosa oil, Neem oil have been reported to be effective in curbing the growth of anthracnose fungus (Jayalakshmi and Seetharaman, 1998). An effective approach for eco-friendly management of chilli anthracnose is the combined application of plant extract of neem (*Azadirachta indica*), mahogany (*Swietenia mahagoni*), and garlic (*Allium sativum*). The combination of extracts from these plants showed significant impact on disease reduction as well as on yield of chilli (Rashid et al., 2015).

Trichoderma species have been reported to effectively control *Colletotrichum* species in chilli with concomitant disease reduction (Boonnratkwang et al., 2007). Moreover, antagonistic bacterial strains (DGg13 and BB133) were found to effectively control *C. capsici* (Intanoo and Chamswarng, 2007). Other biological control agents such as *Bacillus subtilis* and *Saccharomyces cerevisiae* have been reported as antagonistic to microorganisms (Jayelakshmi and Seetharaman, 1998).

Conclusion

Until now, outbreaks of chilli anthracnose have severely affected pepper production. Thus, it is very urgent to accurately identify the chilli anthracnose pathogen for early diagnosis and disease management in the field. Although several researches have been carried out on anthracnose disease of chilli, resistant chilli cultivars for these pathogens have not been commercialized (Park, 2007). Fungicide is normally used to control this disease. But this practice can affect the human health as the fruit of chilli is commonly eaten raw without cooking. Furthermore, continuous chemical use leads to adverse effects including pest resistance and environmental pollution (Lakshmi et al., 2014). Therefore, an integrated management practice and the use of biological control including combined applications of plant extracts leading to organic production of chilli may guarantee a safe and healthy production. However, the best and most effective approach for control of this disease could be the development of high yielding resistant cultivars. So, the development of resistance in chilli should be focused on as it would provide a long lasting remedy.

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