CHAPTER 1

THE INFLUENCE AND CONTROL OF MANGO DISEASES, WITH SPECIFIC REFERENCE TO DISEASES CAUSED BY *BOTRYOSPHAERIA* SPECIES

INTRODUCTION

The mango (*Mangifera indica* L.) belongs to the dicotyledenous family *Anacardiaceae.* This tree is indigenous to India and southern Asia and originated from the Indian/Burmese border region where it has been cultivated for many centuries (Kwee & Chang, 1985). Today, mangoes are cultivated in most tropical and subtropical parts of the world where they are commonly eaten fruits (Prakash & Srivastava, 1987; Schroeder, 1990). Countries that cultivate mangoes commercially, but primarily for local consumption, include India, Pakistan, Indonesia, Mexico, Brazil and the Philippines. The most important mango exporting countries are Australia, South Africa, Israel, Egypt and the United States of America (Johnson, 1992).

The conditions under which mango trees are cultivated, often favour disease development. Mango trees are able to adapt to harsh environments that are normally not conducive to growth of other fruit trees (Wolstenholme *et al.*, 1995). These sub-optimal environmental conditions, however, often cause stress, which reduces the tree's ability to elicit an active defense response to pathogen infection and invasion (Schoeneweiss, 1984). Mango trees, therefore, experience different levels of stress in different environments, which together with varying levels of pathogen inoculum pressure, can trigger symptom development and result in disease expression (Finnemore, 2000).

In South Africa, as with many other countries, mango fruit mainly develop and ripen during the rainy season when prevailing weather conditions are warm with a high humidity, which makes fruit prone to attack by various microorganisms (Reckhaus, 1987; Ramos *et al.*, 1991; Lonsdale, 1993a). A wide diversity of pathogens attack various parts of nursery- and adult mango trees. Anthracnose, blossom blight, powdery mildew, flower malformation, cankers,

twig dieback and bacterial black spot are some of the main problems faced by mango producers world-wide (Prakash & Srivastava, 1987; Wolstenholme *et al.*, 1995). Of the diseases, those caused by fungi contribute the most to production and economic losses (Singh, 1960; Prakash & Srivastava, 1987; Johnson, 1992).

Fungi generally affect mango production through disease development and *Botryosphaeria* spp. are amongst the most common and destructive of these fungi (Johnson, 1992). Anamorphs of *Botryosphaeria* spp., commonly associated with mango, are *Dothiorella* spp., *Nattrassia* spp., *Fusicoccum* spp. and *Lasiodiplodia* spp. (Ramos *et al.*, 1991; Darvas, 1991; Johnson *et al.*, 1991; Johnson, 1992). There is, however, great confusion regarding the taxonomy, classification and identification of these anamorph species (Johnson, 1992; Jacobs & Rehner, 1998; Crous & Palm, 1999). The morphological criteria for identification is generally not enough to differentiate between these species (Jacobs & Rehner, 1998; Denman *et al.*, 2000). For this reason, the naming, synonymy, occurrence and importance of these anamorph species of *Botryosphaeria* from mango have not been clarified yet. Such clarification is, however, needed to assess pathogen epidemiology and efficient future control.

There is a lack of effective control strategies for diseases such as those caused by *Botryosphaeria* spp. associated with mango trees and fruit (Johnson *et al.*, 1991; Peterson *et al.*, 1991; Johnson, 1992), which poses a serious threat to the entire industry. To address the problems with control of *Botryosphaeria* diseases, there is a need to understand the taxonomy and biology of these fungi. This information is also crucial to develop quarantine strategies for preventing further spread of this pathogen to areas where it does not occur. The aim of this review is, therefore, to assess the current information regarding the epidemiology, identification and taxonomy, as well as the control of *Botryosphaeria* diseases.

BOTRYOSPHAERIA DISEASES OF MANGO

Botryosphaeria spp. are mainly saprophytic and endophytic, but occasionally cause extensive disease symptoms on a variety of woody hosts (Von Arx, 1987; Schoeneweiss, 1984; Denman *et al.*, 2000). These species infect through natural openings and wounds, but the infection is usually latent. The disease symptoms are commonly expressed when hosts are stressed with inactivated natural host defence mechanisms (Schoeneweiss, 1979).

Botryosphaeria spp. can attack different parts of the mango tree and fruit, resulting in pre- and postharvest diseases. The pathogen colonizes the blossom as an endophyte, often resulting in blossom blight. The infected axes, florets and fruitlets shrivel and become necrotic. If environmental conditions are favourable for the pathogen, it moves down the main axis and colonize stem tissue, causing twig dieback and extensive cankering of stems and trunks. Infection of unripe fruit in orchards remains latent until fruit start to ripen after harvest. At this stage, the pathogen invasion continues and fruit is colonized, giving rise to a soft brown rot (SBR), a typical body rot and stem end rot (SER) (Johnson *et al.*, 1992; Lonsdale, 1993b).

Preharvest diseases

Blossom blights are common in most mango-growing countries (Kwee & Chang, 1985). Inflorescences are extensively colonised by *Botryosphaeria* species, especially during the rainy season (Darvas, 1991). The early symptoms of blossom blight are inflorescence wilting and production of minute black spots, which later enlarge and coalesce, resulting in shedding of flowers and shriveling and drying of the flower axes (Lonsdale, 1992; Lonsdale, 1993a). The severity of blossom blight is greatly dependent on environmental factors contributing to

induced stress on trees during inflorescence development (Kwee & Chang, 1985; Lonsdale, 1992; Lonsdale, 1993a).

Twig dieback poses a major preharvest problem in various mango producing countries. Infected twigs and stems turn brown, dry out and become necrotic from the tips, backwards. The pathogen most frequently associated with twig dieback of mangoes in Australia closely resembles *Botryosphaeria dothidea* (Johnson, 1992). Ramos *et al.* (1991) investigated mango tip dieback in Florida and found the primary organism responsible to be *Botryosphaeria ribis* Gross. & Duggar or the anamorphs associated with it.

Cankers usually appear as longitudinal cracks in the bark with a brown to black discoloration of the infected area. Latex exudation from the collars is seen in severe cases (Jayasinghe & Silva, 1994). Developing cankers often have a zonate pattern of dark and lighter regions (Maas & Uecker, 1984). Cankerous lesions often develop around and beneath the nodes and later spread above this area (Jayasinghe & Silva, 1994). Conidiomata of the fungus are scattered sub-epidermally throughout the cankers, becoming erumpent with exposed ostioles.

Postharvest infections

A serious threat to the mango industry is postharvest decay. Postharvest losses may be due to various factors, including physiological changes, physical damage, chemical injury or residues and pathological decay (Swart, 1999). When anthracnose, caused by *Colletotrichum gloeosporiodes* (Penzig) Penzig & Sacc. is well controlled, the most economically important postharvest decay of mango in various countries is SER or SBR (Johnson *et al.*, 1991; Sanchote, 1991; Johnson, 1992; Johnson & Sanchote, 1994; Lonsdale, 1993b).

Stem end rot and SBR has been reported from all major mango-growing regions of the world. The term "stem end rot" has been used to describe lesions that develop at the pedicel end of the fruit after harvest, eventually leading to complete fruit decay (Johnson *et al.*, 1991). On the body of mango fruit, decay caused by *Botryosphaeria* spp. is referred to as SBR, which is in essence the same disease as SER. The variation in the incidence of SER and SBR can be related to overall tree health and age, pruning history, fruit maturity at harvest, preharvest spray schedules, postharvest handling and storage conditions and postharvest fungicidal treatments (Johnson, 1992; Johnson & Sanchote, 1994; Wolstenholme & Whiley, 1995; Cooke *et al.*, 1998; Sanchote, 1993b).

Fruit rot lesions appear as water-soaked tissue irregularly radiating from the stem ends or infected areas on the fruit body, which quickly darken and coalesce into irregular circular lesions. Superficial white fungal mycelium may be seen protruding from the pedicel end of fruit. A watery fluid drains from the stem end or ruptures of the fruit surface. As fruit decay and begin to desiccate, fungal fruiting bodies is observed on the surfaces in some instances (Darvas, 1991; Sanchote, 1991; Johnson, 1992; Johnson *et al.*, 1992; Lonsdale, 1993b).

Botryosphaeria spp. can quickly spread from infected to healthy adjacent fruit in a carton (Kruger *et al.*, 1995). This causes significant problems for exporters that usually only detect rotten fruit at the end of the export chain, resulting in significant financial losses (Lonsdale, 1993a; Saaiman, 1996). Since mangoes from South Africa are exported by sea to mainly European countries, fruit are exposed to long cold storage conditions. This makes effective pre- and postharvest control of the pathogen essential to minimize losses at the retail end.

Epidemiology

To formulate an effective control strategy for diseases caused by *Botryosphaeria* spp. it is essential to understand the infection processes and epidemiology of the pathogen (Johnson & Sanchote, 1994). The exact mode of entry of *Botryosphaeria* on mango trees is not known, but natural openings and wounds caused by pruning, insects and sunburn is considered the most likely route of infection (Maas & Uecker, 1984; Johnson 1992; Johnson, 1994; Lonsdale, 1992). Fruit invasion by the pathogen is through the stem ends causing latent infections. After latency is broken, systemic spread of the pathogen can occur (Johnson, 1992; Lonsdale, 1993b). During ripening, levels of natural anti-fungal substances in the fruit are depleted to an extent where the pathogen can easily invade the fruit peel and tissue (Prusky & Keen, 1993), leading to SER or SBR symptom development.

High humidity and movement of water is generally responsible for the release and dispersal of *Botryosphaeria* conidia from limbs of various woody hosts (Weaver, 1979; Sutton, 1981; Creswell & Milholland, 1988). Creswell and Milholland (1988) found that conidia are present in rainwater all year, indicating the importance of rain as a mechanism of pathogen spread. Fruiting structures of *Botryosphaeria* spp. are often produced on old mango tree litter, enabling easy spore dispersal by means of rain splash and wind. As the ostioles open, conidia are easily released and can be spread by splashing raindrops, wind and direct contact with uninfected host tissue (Sutton, 1981; Creswell & Milholland, 1988; Sutton & Davidson, 1983; Maas & Uecker, 1984; Johnson, 1992). Darvas (1991) and Johnson (1992) also commonly detected stem end rot fungi in dead twigs, branches and fallen fruit. The teleomorph stage of the fungus is, however, not often encountered, probably because orchard sanitation programs include the regular removal of fallen twig and leaf litter under trees (Sutton, 1981; Pusey, 1989).

Botryosphaeria spp. can occur endophytically in healthy plant tissue and in plant debris and soil. They can colonise plant tissue through stomata, lenticells and directly on stems (Maas & Uecker, 1984). In many hosts, invasion through lenticels leads to localized infections manifested as sunken necrotic lesions and gum exudation on trunks and limbs. The pathogen resides in lenticels and invades the cortical tissue beneath lenticels when moisture stress develops (Pusey, 1989). The pathogen also has the ability to invade the vascular system of woody hosts (Ramos *et al.*, 1991). Once the pathogen enters the vascular system, it moves quickly down the stem, but with slow lateral movement. Death of the portions above the stem canker may result from tyloses and mycelium clogging the xylem vessels (Maas & Uecker, 1984; Ramos *et al.*, 1991).

Botryosphaeria diseases of stems often follow stress conditions on the mango tree. Such stress is induced by various factors such as mineral deficiency, sunburn, hail, drought and freezing and other environmental factors (Pusey, 1989; Wene & Schoeneweiss, 1980; McPartland & Schoeneweiss, 1984; Schaffer *et al.*, 1988; Ramos *et al.*, 1991). Under these conditions, trees usually have low levels of resistance or tolerance and disease symptoms develop rapidly. McPartland and Schoeneweiss (1984) investigated the mechanism of plants to resist invasion by *Botryosphaeria* species on *Betula alba* and found that an increased frequency of swelling and bursting of fungal hyphal tips after infection occurs in unstressed plants, while little or no effects were observed on hyphae infecting stressed plants. This may be due to a reduction in calcium ions in stressed stems (McPartland & Schoeneweiss, 1984), since it has previously been demonstrated that calcium ions cause *in vitro* swelling and bursting of fungal hyphal tips (Dow & Rubery, 1975). This study indicate that unstressed stems have natural resistance to *Botryosphaeria*, which results from an active biochemical host defense response and that this mechanism is not active in stressed plants (McPartland & Schoeneweiss, 1984).

TAXONOMY OF *BOTRYOSPHAERIA* SPECIES THAT CAUSE DISEASES OF MANGO

The type species of the teleomorph genus *Botryosphaeria*, is *B. dothidea* Ces. & De Not (Sutton, 1980; Johnson, 1992). *Botryosphaeria dothidea* was first described by Cesati and De Notaris from *Fraxinus* sp. when the genus was established in 1863. The fungi treated under this genus have, however, undergone a number of changes since the initial description. Currently, the taxonomy of many species in this genus is unclear and is in serious need of review (Sivanesan, 1984; Rayachhetry *et al.*, 1996; Jacobs & Rehner, 1998; Denman *et al.*, 2000).

In culture and on diseased material, the anamorphs of *Botryosphaeria* is most frequently encountered. The features for species differentiation are often more distinct in the anamorph genera than the teleomorphs (Sutton, 1980; Jacobs & Rehner, 1998; Denman *et al.*, 2000). For this reason, the taxonomy of *Botryosphaeria* spp. largely depends on variation in the anamorph genera. The characters for identification of the anamorphs are, however, poorly described (Sutton, 1980; Morgan-Johnes & White, 1987; Denman *et al.*, 2000). Changes in conidial morphology with maturity also limits the identification process (Laundon, 1973; Rayachhetry *et al.*, 1996; Denman *et al.*, 2000).

Conidia obtained from mango tissue are mostly hyaline, single-celled, ellipsoid to fusoid and distinctly basally truncate (Ramos *et al.*, 1991). Formation of septa in germinating conidia has been reported for various species, but little is known concerning the factors that stimulate this process. Conidia of some species become bi-septate with the middle of the cells becoming darker with maturity, although this phenomenon is not always constant (Maas & Uecker,

1984; Pennycook & Sameuls, 1985). Due to the uncertainty concerning the taxonomic status of some of the anamorphs, many authors have chosen to use only the teleomorph name.

A detailed study of the *Botryosphaeria* spp. is long overdue and should include both morphological and molecular data (Jacobs & Rehner, 1998; Crous & Palm, 1999; Denman *et al.*, 2000; Zhou & Stanosz, 2001). Correct identification of pathogenic species provides the basis for an effective disease control strategy. Due to their importance and predominance on infected tissue, the taxonomy of the anamorphs of *Botryosphaeria* are discussed in detail in this review.

Anamorph taxonomy

Botryosphaeria produces anamorphs that have been variously assigned in the form-genera *Fusicoccum* Corda in Sturm., *Dothiorella* Sacc., *Diplodia* Fr. in Mont., *Lasiodiplodia* Ellis & Everh., *Sphaeropsis* Sacc. and *Phyllosticta* Pers. (Von Arx, 1987; Jacobs & Rehner, 1998). The anamorphs of *Botryosphaeria* commonly associated with mango fruit infection are *D. dominicana* Pet. et Cif., *D. mangiferae* H. et P. Syd. et But., *D.* 'long' (an unnamed *Dothiorella* sp.) and *L. theobromae* (Pat.) Griff. et Maubl., (Johnson, 1992). The identification and characterization of these anamorph species is generally based on differences in morphological characteristics.

The most important morphological characteristics separating *Botryosphaeria* anamorph genera are variation in pycnidia and conidia (Sutton, 1980). *Botryosphaeria* anamorphs can be separated in two distinct groups according to conidial colour. The one group includes genera with hyaline, narrow conidia and the other darker coloured, broader conidia (Jacobs & Rehner, 1998; Denman *et al.*, 2000; Zhou & Stanosz, 2001). It has thus been proposed that all

anamorphs of *Botryosphaeria* should reside in either *Fusicoccum* or *Diplodia* (Sutton, 1980; Maas & Uecker, 1984; Crous & Palm, 1999; Denman *et al.*, 2000).

(I) ***Dothiorella***

Dothiorella species are common on twigs and branches of woody plants and grasses (Von Arx, 1987). The status of the name *Dothiorella* has been in question for many years. Crous and Palm (1999) found, while comparing findings of Berkley (1860) and Saccardo (1884), that they evaluated and described the type of the genus *Dothiorella* on separate occasions. Only small differences were found between their findings (Crous & Palm, 1999). Berkley did not believe in separating the anamorph and teleomorph and treated this genus as *Botryosphaeria*. Saccardo, however, placed the emphasis on anamorphs and resurrected *Dothiorella* to its original state.

Crous and Palm (1999) challenged the validity of *Dothiorella* and synonimised the type species of *Dothiorella* with *Diplodia*. This synonymy was based on the finding that the conidiomata of *Dothiorella pyrenophora* Sacc., the type species of *Dothiorella*, are unilocular to multilocular and conidiophores are branched, septate, holoblastic and give rise to smooth or verriculous, brown, euseptate conidia. This made the *Dothiorella* type species indistinguishable from *Diplodia* (Crous & Palm, 1999). These findings emphasises that the taxa with hyaline or dark conidia, which was previously referred to as *Dothiorella,* needs careful re-evaluation for the correct taxonomic placement in *Diplodia* or *Fusicoccum* (Crous & Palm, 1999; Denman *et al.*, 1999).

Fungi resembling *Dothiorella* or *Fusicoccum* from mango have generally been placed in *Dothiorella.* Sutton (1980) and Morgan-Jones and White (1987) shared the view of Saccardo

that the name *F. aesculi* Corda was not missapplied to a group of fungi with hyaline, aseptate conidia, and that fungi classified as *Dothiorella,* should best reside in *Fusicoccum.* Johnson (1992) considered this view in detail based on Australian isolates from mango and suggested that *D. dominicana* fits the description of the *F. aesculi*, which is the anamorph of *B. dothidea* (Morug. Fr.) Ces. & de Not. Various authors suggested that other *Dothiorella* spp. should be re-evaluated and correctly incorporated in *Fusicoccum* (Sutton, 1980; Maas & Uecker, 1984; Johnson, 1992; Crous & Palm, 1999).

Some of the most important species recognized worldwide as causal agents of major pre- and postharvest losses in mango are *D. dominicana, D. mangiferae* and to a lesser extent *D. aromatica* (Johnson, 1992). The final taxonomic status of these species has not yet been clarified, but is currently being investigated (Slippers, personal communication). Because of the uncertain status of these names, they are used as per their original or translated description in this review (Table 1; p 37).

(II) ***Fusicoccum***

The genus *Fusicoccum* was first described in 1829 and the type species is *F. aesculi* Corda., but the status of *Fusicoccum* and the type has been the source of confusion for many years (Sutton, 1980; Maas & Uecker, 1984; Jacobs & Rehner, 1998; Crous & Palm, 1999; Zhou & Stanosz, 2001). Sutton's (1980) description of *Fusicoccum* suggested that it resides in the Coelomycetes with fusiform, hyaline, aseptate conidia, produced holoblastically in eustromatic conidiomata. He showed that the conidia of *Fusicoccum* are produced with a single precurrent proliferation. *Fusicoccum* was regarded as an appropriate genus for anamorphs of *B.ribis* Grossenb. & Dugg. (currently known as *B. parva*) and *B. dothidea* (Sutton, 1980; Denman *et al.*, 2000). Sutton's view of *Fusicoccum* was later shared by Maas

and Uecker (1984). Pennycook and Sameuls (1985) also agreed with this description, but stated that the original description was based on the immature state of the fungus, since all pycnidia examined were covered with host tissue. These authors also believe that most conidiogenous loci appear to produce only one holoblastic conidium. It was observed that older conidiogenous cells of *F. aesculi* were enteroblastic and proliferated precurrently at the same level. This observation was confirmed by Crous and Palm (1999).

Sutton (1980) examined Petrak's description of *Fusicoccum* (Petrak & Cifferi, 1930) and found that he referred to the *Fusicoccum*-like species as *Dothiorella*, citing the species as the conidial state of *B. berengeriana*. This view of Petrak is believed to have triggered the confusion regarding the taxonomy of *Fusicoccum*, *Dothiorella* and other *Botryosphaeria* anamorphs with hyaline conidia (Sutton, 1980; Denman *et al.*, 2000). The appropriate genus name for hyaline conidial anamorphs under *Botryosphaeria* should be *Fusicoccum* rather than *Dothiorella*, since the older name should take priority (Sutton, 1980; Johnson, 1992; Jacobs & Rehner, 1998; Crous & Palm, 1999; Denman *et al.*, 2000). According to further findings by Sutton (1980), the generic concept of *Fusicoccum* should be expanded to include septate, darker conidia, since *Fusicoccum* is an older name than *Diplodia,* which also includes *Botryosphaeria* anamorphs. Pennycook and Samuels (1985) examined Saccardo's specimen of *F. aesculi* and described three species of *Fusicoccum,* of which all three had conidiogenous cells proliferating precurrently, with the first formed conidia appearing to be formed holoblastically. They associated *F. aesculi* with the broad description of *Diplodia* except that *F. aesculi* was reportedly not becoming brown and septate with age. Crous and Palm (1999), however, re-evaluated the taxonomic status of *Botryosphaeria, Dothiorella* and *Fusicoccum* and provided a new description for the type of *F. aesculi* Corda (Table 1; p37).

(III) ***Nattrassia***

Nattrassia mangiferae (Nattrass) Sutton et Dyko is the only known species of this genus. The genus was first described from plum, apricot and apple isolates by Nattrass, but has since been reported from many woody hosts in various tropical and subtropical countries worldwide (Sutton & Dyko, 1989). The arthric synamorph is known as *Scytaldium dimidiatum* Pesante, and mainly causes dermatological disease in humans (Frankel & Rippon, 1989).

Sutton and Dyko (1989) examined differences between *Hendersonula toruloidea* Nattrass, *Fusicoccum eucalypti* da Camara, *Hendersonia cypia* Nattrass and *Dothiorella mangiferae* and reduced them to synonymy with *N. mangiferae* (Sutton & Dyko, 1989; Johnson, 1992). Johnson (1992), however, suggested that *Nattrassia* and *D. mangiferae* might be a synonym of *Fusicoccum.* This synonymy was justified based on the similarity between conidia and conidiogenous cells of *N. mangiferae, D. mangiferae* and a *Fusicoccum* sp.

In culture, *N. mangiferae* produces colonies of greyish to black fluffy mycelium with gregarious, partly immersed, discrete conidiomata on oatmeal agar. A radially dendritic, dark gray mycelium is found when cultures are grown on potato dextrose agar (PDA). Sutton and Dyko (1989) provided a description for the type species *N. mangiferae,* which is referred to in this review (Table 1; p 37).

(IV) ***Lasiodiplodia***

The fungus, *Lasiodiplodia theobromae* Pat., is commonly known as a saprophyte and wound invading pathogen of many tropical and sub-tropical crops, causing pre- and postharvest problems in many countries (Punithalingam, 1979; Punithalingam, 1980; Sutton, 1980; Von

Arx; 1987). *Lasiodiplodia theobromae* infection of mango has been reported on from the early 1900's (Punithalingam, 1980).

Lasiodiplodia has been referred to under various genera and synonyms were drawn to it by various authors (Punithalingam, 1976; Punithalingam, 1980). It was previously also known as *Botryodiplodia theobromae* Pat. (Punithalingam, 1976; Punithalingam, 1980; Von Arx, 1987; Crous & Palm, 1999), however, *Botryodiplodia* was synonomized with *Lasiodiplodia* by Petrak & Sydow (Sutton, 1980; Von Arx, 1987). The characteristics of the anamorph species justify the synonymy of *Diplodia* and *Botryodiplodia* (Punithalingham, 1976; Punithalingam, 1980; Crous & Palm, 1999) (Table 1; p37). *Lasiodiplodia theobromae* has previously been reported as the anamorph of *Physalospora rhodina* Berk. & Curt. apud Cooke (Punithalingam, 1980; Sutton, 1980). It is, however, now generally excepted to be the anamorph of *Botryosphaeria rhodina* (Cooke) Von Arx (Von Arx, 1987).

CONTROL STRATEGIES

Infection of mango trees and fruit by *Botryosphaeria* spp. can result in many different disease symptoms of which blossom blight, twig and stem dieback, cankering and fruit rots are of major importance. The development of control for economically important pre- and postharvest diseases caused by these fungi should include a focus on pathogen epidemiology. The fungi exist endophytically in the mango tree, spread systemically through the vascular system and expresses symptoms pre- and postharvestly if pathogen invasion and colonisation is not inhibited chemically or biologically.

Preharvest control

Disease incidence variation seems to relate to the fluctuation and extent of latent infections of *Botryosphaeria* in fruit and trees (Johnson, 1992; Lonsdale, 1993b). Latent infections can be influenced by orchard fungicide spraying, orchard sanitation, cultivar resistance, climate and tree age (Johnson *et al.*, 1992; Sangchote, 1993a; Johnson & Sanchote, 1994; Cooke *et al*, 1998). Some preharvest control measures aimed at reducing such infections, therefore, include planting for disease resistant or tolerant cultivars, reduction of potential wounds and limiting the chance of preharvest fungal inoculum deposition (Singh, 1960; Johnson & Sangchote, 1994; Sangchote, 1998b). Mismanagement and neglect of orchards is often associated with an increase in preharvest diseases.

Preharvest fungicidal sprays or the application of biocontrol agents such as *Bacillus licheniformis* (De Villiers & Korsten, 1996), and covering fruit with polyethylene caps (Kitagawa *et al.*, 1992; Johnson & Sanchote, 1994; Sanchote, 1993b), was found to reduce the incidence of fruit rots. Chemical fungicides such as flusilazol (under dryland conditions), iprodione, imazalil, prochlaraz, manganese chloride and triadimenol was shown to have a certain level of effectiveness against *Botryosphaeria* spp. causing fruit rots, but effectiveness varied with area and cultivar (Peterson *et al.*, 1991; Prusky, 1991; Johnson, 1992; Gunasekaran & Weber, 1996). Due to the reported incidence of build-up of pathogen resistance with the use of certain fungicides, most of these chemicals are either not used or alternated with copper oxychloride sprays. Copper oxychloride has to date proven to the most effective fungicide against many mango diseases (Spalding, 1982; Peterson *et al.*, 1991; Prusky, 1991; Johnson, 1992). Copper oxychloride is currently also the only preharvest fungicide registered for use on fruit destined for export from South Africa (Boshoff *et al.*, 1994).

Postharvest control

The most effective postharvest disease control strategy usually starts with an effective preharvest protection program. Preharvest practices, however, does not achieve consistent disease control. This makes it necessary to use postharvest fruit treatments to effectively control SER and SBR (Prusky, 1991; Johnson, 1992; Johnson & Sanchote, 1994). Such postharvest approaches are focussed on the delay of symptom development.

In recent years, the emphasis has been on the development and improvement of postharvest practices such as irradiation, warm water treatments and controlled atmosphere and low temperature storage (Pelser & Lesar, 1989; Johnson *et al.*, 1990; Medlicott *et al.*, 1990; Prusky, 1991; Johnson, 1992). The alternate use of increased CO_2 levels has proven to be useful in controlling postharvest pathogens during long term, low-temperature storage, but only with certain cultivars (Pelsar & Lesar, 1989; Prusky, 1991; Kobiler *et al.*, 1998; Meiburg *et al.*, 1998). Dipping of fruit in hot water (55°C) amended with registered chemicals such as prochloraz, can adequately control most of the superficial infections and prevent transmission of inoculum (Pelsar & Lesar, 1989; Johnson, 1992; Johnson & Sangchote, 1994). Prochloraz is, however, currently not registered for use on fruit destined for the European markets due to product clearance not given by countries such as France. Similarly, exposure of fruit to short wave infrared radiation, for three minutes has been shown to be effective in controlling SBR, however, this can result in lenticell damage and this technique is therefore not utilised commercially (Johnson *et al.*, 1990; Prusky, 1991; Johnson, 1992; Saaiman, 1995). Of all these control measures, only hot water fruit dips are currently commercially used in packhouses in South Africa (Saaiman, 1995).

Biological control as an alternative postharvest control measure is at an early stage of commercialisation (Gunasekaran & Weber, 1996). A warm water dip with *B. lichiformis*, followed by reduced concentrations of procloraz was found to effectively control various mango diseases, including fruit rots (De Villiers & Korsten, 1996). Even more effective control was achieved when 10% ethanol was used before applying the antagonist (De Villiers & Korsten, 1996). The main problem facing commercialisation of biological control is inconsistency in the level of control, which needs to be addressed through more effective product formulations (Korsten *et al.*, 1993).

Integrated control

With increased public concern over health risks, environmental pollution and the possibility of pathogen resistance developing against chemicals, it has become important to explore alternative measures of control (Johnson & Sanchote, 1994). Levels of endophytic colonisation in trees have been effectively reduced when commercial pruning programs in mango orchards have been synchronized with preharvest control measures (Cooke *et al.*, 1998). Canker formation can be minimized by preventing wounding and by pruning cankered or dead limbs of mango trees in the orchard. The trees respond well with vigorous growth after pruning with the addition of protective fungicidal sprays (Johnson, 1992; Johnson & Sanchote, 1994). This reduces pathogen inoculum and assists the tree to outgrow pathogen infection. Tree manipulation strategies will, however, only succeed if stress is minimized during all critical growth and dormancy periods (Johnson, 1992; Wolstenholme & Whiley, 1995). The latest focus on alternative strategies is the development of slow-ripening tropical fruit cultivars. This could facilitate long storage of fruit and subsequently delay disease development (Sangchote, 1991; Finnemore, 2000).

CONCLUSIONS

The export value of fresh mango fruit and its importance in the diet of people in many developing countries makes mango one of the most important fruit crops in the world. Due to the popularity of the crop and its wide distribution, mango is commonly cultivated under sub-optimal environmental conditions, often resulting in stress conditions conducive to pathogen attack. The high temperature and humid condition during fruit development favours infection and colonisation of fungal pathogens. Mango production is, therefore, seriously threatened by fungi that attack mango trees, flowers or fruit.

Currently, the most economically important diseases of mango trees and fruit are caused by *Botryosphaeria* species. These species are recognised endophytes of mango trees, however, the endophytes can become pathogenic and cause diseases of all the tree and fruit parts. The pathogenic nature of *Botryosphaeria* spp. is easily induced when trees are predisposed to stress conditions such as water stress, sunburn and mineral deficiencies. *Botryosphaeria* spp. infects through natural openings and wounds in the host tissue. After infection, the pathogen can remain quiescent or quickly enter the vascular system, causing vein discoloration and clogging of vessels. The restricted nutrient flow and rapid tissue invasion initiates the expression of disease symptoms such as blossom blights, twig diebacks, cankering and fruit rots of mango.

Various anamorph genera of *Botryosphaeria* are readily encountered on mango trees and fruit and the identification and characterisation of the *Botryosphaeria* spp. are based on morphological characteristics of the anamorphs. Due to the similarities between these anamorphs, considerable confusion has surrounded the taxonomy and epidemiology of the

Botryosphaeria spp. infecting mango world-wide. Many different species in *Hendersonia*, *Dothiorella*, *Nattrassia*, *Fusicoccum* and *Lasiodiplodia* have previously been identified as mango pathogens and the current generic concepts are, therefore, in need of urgent revision.

Limited success in controlling mango diseases caused by *Botryosphaeria* spp., emphasise the need and importance of developing effective alternative control strategies. The lack of tolerance in the more than 100 mango cultivars world-wide to *Botryosphaeria* infection, is a factor for major concern. Furthermore, there has recently been an emphasis on quarantine to prevent the further spread of new or exotic pathogens to foreign countries. This emphasises the need for revision of the taxonomy of the *Botryosphaeria* pathogens involved in mango diseases, as identification is the first step in developing effective control strategies and quarantine regulations.

REFERENCES

Berkley, M.J. 1860. Outlines of British Fungology – Lovell Reeve, London, UK.

Boshoff, M., Slabbert, M.J. & Korsten, L. 1995. Effect of detergent sanitizers and postharvest diseases of avocado. *South African Growers' Association Yearbook* 18: 96–98.

Cesati, V. & De Notaris, G. 1863. Schema di classificazione degli sferiacei italici aschigeri piu o meno apparleneti al genere *Sphaeria* nell antico significato attribuitogli da Persoon. *Commentario della Societa Crittogamologica Italiana* 1: 177-240. (English translation).

Creswell, T.C. & Milholland, R.D. 1988. Spore release and infection periods of *Botryosphaeria dothidea* on blueberry in North Carolina. *Plant Disease* 72: 342–346.

Cooke, A.W., Van der Kruyssen, A. & Johnson, G.I. 1998. The effect of commercial pruning on colonization of mango by endophytic *Dothiorella* species. In: Post-harvest handling of tropical fruit. Proceedings of an International Congress, Chaing Mai, Thailand. Champ, B.R., Highley, E. and Johnson, G.I. (Eds.). pp. 294- 298. Australian Centre for International Agricultural Research, Canberra.

Crous, P.W. & Palm, M.E. 1999. Reassessment of the anamorph genera *Botriodiplodia, Dothiorella* and *Fusicoccum*. *Sydowia* 51: 167–175.

Darvas, J.M. 1991. *Dothiorella dominicana*, a new mango pathogen in South Africa. *Phytophylactica* 23: 295-298.

Denman, S., Crous, P.W., Taylor, J.E., Kang, J., Pascoe, I. & Wingfield, M.J. 2000. An overview of the taxonomic history of *Botryosphaeria*, and a re-evaluation of its anamorphs based on morphology and ITS rDNA phylogeny. *Studies in Mycology* 45: 129-140.

De Villiers, E.E. & Korsten, L. 1996. Alternative strategies for the control of mango fruit diseases. *South African Mango Growers' Association Yearbook* 16: 61-64.

Dow, J.M. & Rubery, P.H. 1975. Hyphal tip bursting in *Mucor rouxii:* Antagonistic effects of calcium ions and acid. *Journal of General Microbiology* 91: 425–428.

Finnemore H J. 2000. An overview of the South African mango industry (past and future) 1-11 pp. http://students.washington.edu/melliott/arbutus/natt.htm

Frankel, D.H. & Rippon, J.W. 1989. *Hendersonula toruloidea* infection in man. *Mycopathologia* 105: 175–186.

Gunasekaran, M. & Weber, D.J. 1996. Molecular Biology of the Biological Control of Pests and Diseases of Plants. pp. 31-35. CRC Press, Inc.

Jacobs, K.A. & Rehner, S.A. 1998. Comparison of cultural and morphological characters and ITS sequencing in anamorphs of *Botryosphaeria* and related taxa. *Mycologia* 90: 601–610.

Jayasinghe, C.K. & Silva, W.P.K. 1994. Foot canker and sudden wilt of *Hevea brasiliensis* associated with *Nattrassia mangiferae*. *Plant Pathology* 43: 938–940.

Johnson, G.I. 1992. Biology and control of stem end rot pathogens of mango. Ph.D. thesis. University of Queensland, Queensland, Australia.

Johnson, G.I., Sanchote, S. & Cooke, A.W. 1990. Control of stem end *rot (Dothoirella dominicana*) and other postharvest diseases of mangoes (cv. Kensington Pride) during short and long-term storage. *Tropical Agriculture* (*Trinidad*) 67: 183-187.

Johnson, G.I., Cooke, A.W., Mead, A.J. & Wells, I.A. 1991. Stem-end rot of mangoes in Australia: Causes and control. *Acta Horticulturae* 291: 288-295.

Johnson, G.I., Mead, A.J., Cooke, A.W. & Dean, J.R. 1992. Mango stem end rot pathogens – Fruit infection by endophytic colonisation of the inflorescence and pedicel. *Annals of Applied Biology* 120: 225–234.

Johnson, G.I. 1994. Part III. Mango: Stem-end rot. In: Compendium of tropical fruit diseases. Ploetz, R.C., Zentmyer, G.A., Nishijima, W.T., Rohrbach, K.G. & Ohr, H.D. (Eds.). pp. 36-37. APS Press, St Paul, Minnesota.

Johnson, G.I. & Sangchote, S. 1994. Control of post-harvest diseases of tropical fruits: Challenges for the 21st century. In: Post-harvest handling of tropical fruit. Proceedings of an International Congress, Chaing Mai, Thailand. Champ, B.R., Highley, E. and Johnson, G.I. (Eds.). pp. 140-161. Australian Centre for International Agricultural Research, Canberra.

Kitagawa, H., Manabe, K. & Esguerra, E.B. 1992. Bagging of fruit on the tree to control disease. *Acta Horticulturae* 321: 871-875.

Kobiler, I., Reved, R., Artez, L. & Prusky, D. 1994. Antifungal compounds regulating quiescent disease in mango. In: Post-harvest handling of tropical fruit. Proceedings of an International Congress, Chaing Mai, Thailand. Champ, B.R., Highley, E. and Johnson, G.I. (Eds.). pp. 109–114. Australian Centre for International Agricultural Research, Canberra.

Korsten, L., De Villiers, E.E. & Lonsdale, J.H. 1993. Biological control of mango postharvest diseases in the packhouse. *South African Mango Growers' Association Yearbook* 13: 117-121.

Kruger, F.J., Goodchild, L., Schroeder, W. & Nel, A. 1995. Current mango research initiatives of the post-harvest section at the research institute for tropical and subtropical crops. *South African Mango Growers' Association Yearbook* 15: 63-66.

Kwee, L.T. & Chang, K.K. 1985. Diseases and disorders of mango in Malaysia. pp. 1-23. Tropical Press, Malaysia.

Laundon, G.F. 1973. *Botryosphaeria obtusa, B. stevensii* and *Otthia spiraeae* in New Zealand. *Transactions of the British Mycological Society* 6: 369-374.

Lonsdale, J.H. 1992. Etiology and control of some mango blossom diseases in Transvaal. MSc thesis. University of Pretoria, Pretoria.

Lonsdale, J.H. 1993a. Mango diseases in South Africa. *South African Mango Growers' Association Yearbook* 13: 89-92.

Lonsdale, J.H. 1993b. Preliminary results on the mode of infection of *Nattrassia mangiferae* in mango. *South African Mango Growers' Association Yearbook* 13: 97-99.

Maas, J.L. & Uecker, F.A. 1984. *Botryosphaeria dothidea* cane canker of thornless blackberry. *Plant Disease* 68: 720–726.

McPartland, J.M. & Schoeneweiss, D.F. 1984. Hyphal morphology of *Botryosphaeria dothidea* in vessels of unstressed and drought-stressed stems of *Betula alba*. *Phytopathology* 74: 358-362.

Medlicott, A.P., Sigrist, J.M.M. & Sy, O. 1990. Ripening of mango following low temperature storage. *Journal of the American Society of Horticultural Science* 115: 430-444.

Meiburg, G.F., Hofman, P.J., Smith, L.G., Cooke, A.W. & Baker, J.A. 1998. Quality of Kensington mangoes after short duration exposure to high carbon dioxide concentrations. In: Post-harvest handling of tropical fruit. Proceedings of an International Congress, Chaing Mai, Thailand. Champ, B.R., Highley, E. and Johnson, G.I. (Eds.). pp. 55-60. Australian Centre for International Agricultural Research, Canberra.

Morgan-Jones, G. & White, J.F. Jr. 1987. Notes on *Coelomycetes*. II. Concerning the *Fusicoccum* anamorph of *Botryosphaeria ribis*. *Mycotaxon* 30: 117–125.

Pelser, P. du T & Lesar, K. 1989. Decay control in South African mangoes by flusilazol, penconazole and procloraz during simulated shipment to Europe. *Aspects of Applied Biology* 20: 41-48.

Pennycook, S.R. & Samuels, G.J. 1985. *Botryosphaeria* and *Fusicoccum* species associated with ripe fruit rot of *Actinidia deliciosa* (kiwifruit) in New Zealand. *Mycotaxon* 24: 445–458.

Peterson, R.A., Johnson, G.I., Schipke, L.G. & Cooke, A.W. 1991. Chemical control of stem end rot in mango. *Acta Horticulturae* 291: 304-307.

Petrak, F. & Cifferi, R. 1930. Fungi dominicani. *Annales Mycologici* 28: 411.

Prakash, O.M. & Srivastava, K.C. 1987. Mango diseases. In: Mango diseases and their management. pp. 1. Today and Tomorrow's Printers and Publishers. New Deli.

Prusky, D. 1991. Mango diseases: An overview. *Acta Horticultura* 291: 279-287.

Punithalingam, E. 1976. *Botryodiplodia theobromae. CMI Description of pathogenic fungi and bacteria* no. 519.

Punithalingam, E. 1979. Plant diseases attributed to *Botryosphaeria theobromae*. pp 123. J.Cramer, Germany.

Punithalingam, E. 1980. Plant diseases attributed to *Botryodiplodia theobromae* Pat. pp. 42-43. J. Cramer. Germany.

Prusky, D. & Keen, N.T. 1993. Involvement of preformed antifungal compounds in the resistance of subtropical fruits to fungal decay. *Plant Disease* 77: 114-119.

Pusey, P.L. 1989. Influence of water stress on susceptibility of non-wounded peach bark to *Botryosphaeria dothidea. Plant Disease* 73: 1000–1003.

Ramos, L.J., Lam, S.P., McMillan, R.J. & Narayanan, K.R. 1991. Tip dieback of mango (*Mangiferae indica*) caused by *Botryosphaeria ribis. Plant Disease* 75: 315–318.

Rayachhetry, M.B., Blakeslee, G.M., Webb, R.S. & Kimbrough, J.W. 1996. Characteristics of the *Fusicoccum* anamorph of *Botryosphaeria ribis*, a potential biological control agent for *Melaleuca quinquenervia* in South Florida. *Mycologia* 88: 239-248.

Reckhaus, P. 1987. *Hendersonula* dieback of mango in Niger. *Plant Disease* 71: 1045.

Saaiman, W. C. 1995. Short wave infra-red radiation as an alternative to the hot water bath for the control of post-harvest diseases in mango. *South African Mango Growers' Association Yearbook* 15: 86–89.

Saaiman, W.C. 1996. Preliminary report on the time of infection of the soft brown rot pathogen *Nattrassia mangiferae* in mango. *South African Mango Growers' Association Yearbook* 16: 55–57.

Saccardo, P.A. 1884. *Sylloge Fungorum onium hucusque cognitorum* 3: 1–860.

Sangchote, S. 1991. *Botryodiplodia* stem end rot of mango and its control. *Acta Horticulturae* 291: 296–304.

Sangchote, S. 1993a. Fruit rots of mangosteen and their control. In: Post-harvest handling of tropical fruit. Proceedings of an International Congress, Chaing Mai, Thailand. Champ, B.R., Highley, E. and Johnson, G.I. (Eds.). pp. 81-86. Australian Centre for International Agricultural Research, Canberra.

Sangchote, S. 1993b. Effect of fruit bagging, fruit position, cultivar and post-harvest treatment on post-harvest disease of mangoes. In: Post-harvest handling of tropical fruit. Proceedings of an International Congress, Chaing Mai, Thailand. Champ, B.R., Highley, E. and Johnson, G.I. (Eds.). pp. 63-66. Australian Centre for International Agricultural Research, Canberra.

Schaffer, B., Larson, K.D., Snyder, G.H. & Sanchez, C.A. 1988. Identification of mineral deficiencies associated with mango decline by DRIS. *Hortscience* 23: 617-619.

Schoeneweiss, D.F. 1979. Protection against stress disposition to *Botryosphaeria* cankers in containerised *Cornus stolonifera* by soil injection with benomyl. *Plant Disease Reporter*: 63: 896-900.

Schoeneweiss, D.F. 1984. The role of environmental stress in diseases of woody plants. *Plant Disease* 56: 308–314.

Schroeder, W. 1990. Origin of the mango. In: Mangoes. pp. 100-102. Citrus and Subtropical Fruit Research Institute, Nelspruit.

Singh, L.B. 1960. Mango. In: The Mango. pp 320-343. World Crop Series. Interscience Publishers Inc., New York.

Sivanesan, A. 1984. The bitunicate ascomycetes and their anamorphs. pp 127-139. J. Cramer, Germany.

Spalding, D.H. 1982. Resistance of mango pathogens to fungicides used to control postharvest diseases. *Plant Disease* 66: 1185-1186.

Sutton, B.C. 1980. The *Coelomycetes*. Fungi Imperfecti with pycnidia, acervuli and stroma. pp. 32, 41. CMI, Kew, Surrey, England.

Sutton, B.C. & Davidson, E.M. 1983. Three stromatic coelomycetes from Western Africa. *Transactions of the British Mycological Society* 81: 291-301.

Sutton, B.C. & Dyko, B.J. 1989. Revision of *Hendersonula. Mycological Research* 93: 466–488.

Sutton, T.B. 1981. Production and dispersal of ascospores and conidia of *Physalospora obtusa* and *Botryosphaeria dothidea* in apple orchards. *Phytopathology* 71: 584-589.

Swart, G.M. 1999. Comparative studies of *Colletotrichum gloeosporoides* from avocado and mango. Ph.D. Thesis. University of Pretoria, Pretoria.

Sydow, H. & Sydow, P. 1919. Mykologische mitteilungen. *Annales Mycologici* 17: 33-47.

Von Arx, J.A. 1987. Plant-pathogenic fungi. 203–204 pp. J. Cramer, Berlin, Germany.

Weaver, D.J. 1979. Role of conidia of *Botryosphaeria dothidea* in the spread of peach tree gummosis. *Phytopathology* 69: 330–334.

Wene, E.G. & Schoeneweiss, D.F. 1980. Localized freezing predisposition of *Botryosphaeria* canker in differentially frozen woody stems. *Canadian Journal of Botany* 58: 1455-1458.

Wolstenholme, B.N. & Whiley, A.W. 1995. Ecophysiology of the mango tree as a basis for pre-harvest management. *South African Mango Growers' Association Yearbook* 15: 10-17.

Zhou, S. & Stanosz, G.R. 2001. Relationships among *Botryosphaeria* species and associated anamorphic fungi inferred from the analyses of ITS and 5.8S rDNA sequences. *Mycologia* 93: 516–527.

Table 1. Description of *Botryosphaeria* found on mango

	F.aesculi Crous & Palm (1999)	*D. dominicana* Petrak & Cifferi (1930) Johnson (1992)	*D. mangiferae* Sydow & Sydow (1919) Johnson (1992)	*D. aromatica* Darvas (1991) (Translation)	*N. mangiferae* Sutton & Dyko (1989)	*L. theobromae* Punithalingam (1980)
Conidiomata						
* Stroma	Eustromatic	Eustromatic	Eustromatic	Eustromatic	Eustramatic	Eustromatic
* Locule	Uni- to multiloculate	Uni- to multiloculate	Uni- to multiloculate	Uni- to multiloculate	Uni- to multiloculate	Uni- to multiloculate
	Locules ostiolar	Locules ostiolar	Locules ostiolar	Locules ostiolar	Locules ostiolar	Ostioles absent
* Size	100 - 300um diameter	250um diameter				
* Paraphysis	Absent	Absent			Absent	Cylindrical, sepate
Conidiogenous						
Cells						
* Shape	Cylindrical	Cylindrical	Filiform	Cylindrical	Lageniform to ampuliform	Cylindricqal
* Conidiophore	Conidiophore simple			Conidiophore simple	Conidiophores absent	Conidiophores absent
* Colour	Hyaline, smooth	Hyaline	Hyaline	Hyaline	Hyaline	Hyaline
* Septation	0 - 1 septate	Aseptate	Aseptate	Aseptate	Aseptate	Aseptate
* Cell size	22 um	5 - 10um	5 - 8um	6 - 16 (-20) um		
* Base size	1.5 - 2.5 um	2 - 2.5 um	2um	2 um		
Conidia						
*Shape	Fusiform to elipsoid	Fusiform to clavate	Fusiform to elipsoid	Fusiform to clavavate	Fusiform to ellipsoid	Ellipsoid
	Straight	Straight to slightly curved	Slightly curved	Straight to slightly curved	Straight to slightly curved	Straight
* Apex	Subobtuse	Rounded	Rounded	Rounded		Truncate
* Base	Truncate	Truncate	Tapered to flat	Tapered		Truncate
	Smooth	Granular		Granular	Smooth	Longitudinal striations
* Cell wall	Thin	Thin	Thin	Thin	Thin	Thick
* Immature	Hyaline	Aseptae	Aseptate	Aseptate	Aseptate	Aseptate
	Aseptate	Hyaline	Hyaline	Hyaline	Hyaline	Hyaline
* Mature	Uni- to biseptate	Uni- to bisepate			Uni- to biseptate	Uniseptate
	Vericulouse	Vericulouse			Verucolouse	Dark brown
* Length	18 - 25 (-30) um	13 - 16.2 (15.6) um	9 - 14 (12.8) um	16 - 23 (22.8) um	10 - 16 (21) µm	18 - 30 um
* Width	4 - 4.5 (-5) um	4.5 - 4.7 um	3.5 - 5.5 (5.0) um	3.9 - 5.5 (4.6) um	3.5 - 6.5 µm	10 - 15 um