Dynamics and Management of Major Postharvest Fungal Diseases of Mango Fruits

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Abstract
Mango is one of the most popular fruit grown throughout the tropics and subtropics region of the world. It is one of the most desirable fruit in the international market because of its delicious taste and high caloric value. However, mango is affected by a number of diseases at all stages of its development, right from the plants in the nursery to the fruits in storage or transit. The mango tree and more especially the fruit is the host of a large number of pathogens among which, fungi could be major agents of fruit rot. Pre-harvest and postharvest diseases can reduce fruit quality and cause severe losses. The observable external symptoms often only become apparent after ripening, by which it is usually equated with the edibility of the fruit and causing serious losses during storage. The economic costs of such postharvest losses are higher than the field losses. The chemical based strategies have been so far dominating for management of mango diseases. However, because of the increasing concern over residual toxicity resulting from the wide spread use of synthetic fungicide and proliferation of resistance in the pathogen populations, attention has focused nonchemical strategies. The trend to explore new alternatives to increase storage life has to give priority to methods that reduce horticultural produce decay but concurrently avoid health or environmental negative impact. The most logical approach is known as integrated disease management, which is being used for few important diseases of mango. A review of the etiology and dynamics of major postharvest disease of mango are provided below as background for the various approaches that have been used to manage the diseases.

Introduction
Mango (*Mangifera indica* L.) is one of the most popular fruits grown throughout the tropics and subtropics worldwide (Alemu *et al*., 2014b). It is one of the most desirable fruits in the international market because of its delicious taste and high caloric value (Diedhiou *et al*., 2007). India is the world's largest producer; with shares around 56% of total global production .The other major mango producing countries are China, Mexico, Thailand, Indonesia, Pakistan, Nigeria, Philippines, Brazil, Egypt and Haiti (Swart, 2010).

Mango is an important component of the diet in many countries in the subtropics and tropics. In regions of the world that have experienced low living standards and serious nutritional deficiency, their attractiveness and flavor have also enhanced the quality of life (Mukherjee and Litz, 2009). However, mango production is consternated by a number of diseases at all stages of its development, right from the seedling in the nursery to the fruits in storage or transit. Field diseases result in the crop loss while postharvest diseases are directly linked with the losses in export and domestic market (Prakash, 2004).

Because of their high moisture and the nutrient reserve, mango fruits are highly susceptible to different pathogenic fungi during the period between harvest and consumption. Being highly perishable, mango fruits have to be marketed immediately after harvest. The postharvest loss of mango is up to 17– 36 % (Haggag, 2010). The mango tree and more especially the fruit is the host of a large number of pathogens among which fungi could be major agents of fruit rot after harvest in the world (Diedhiou *et al*., 2007).

Prevention is the only effective means of reducing losses from most mango diseases. Chemical are the main recourses used to prevent and control the disease however the residue poses potential health hazard and environmental contamination (Alemu *et al*., 2014a). Therefore, the issue facing mango production and in particular disease control is, therefore, managing the plant disease severity below the economic threshold following ecologically safe, economically viable and easily operational procedures. The integrated disease management (IDM) strategy is targeted to achieve this objective. The IDM is structured to use an assortment of procedures rather than relying only on fungicides to control the disease (Parakash, 2004). This review paper concentrates on the etiology of major important postharvest diseases of mango fruit, the weather conditions conducive to disease development and methods for control.

Major postharvest disease of mango
Mango Anthracnose
Occurrence and Economic Importance
Anthracnose caused by *Colletotrichum gloeosporioides* (Penz.) Penz and Sacc is the most serious disease widely distributed in all mango growing regions of the world and is a major constraint on the expansion of export trade of mango (Sangeetha and Rawal, 2008). It is the major disease limiting fruit production in all countries where

mango is grown; especially where high humidity prevails during the cropping season; in this condition the disease incidence could reach almost 100 % (Akem, 2006; Haggag, 2010). The disease occurs at any stage of fruit growth (Yenjit *et al*., 2004). Typically, the pathogen mummifies immature fruit and produces sunken necrotic lesions on different organs including fruits, leaves, shoots and flower. Infection often reduce tree vigor and productivity and cause sever postharvest fruit losses (Rivera-Vargas *et al*., 2006). The postharvest phase is the most damaging and economically significant phases of the disease worldwide. It directly affects the marketable fruit rendering it worthless. This phase is directly linked to the field phase where initial infection usually starts on young twigs and leaves and spread to the flowers, causing blossom blight and destroying the inflorescence and even preventing fruit set (Akem, 2006).

Biology and Host Range

The occurrence of *C. gloeosporioides* on a wide range of perennial and other cash crops and on tropical fruit crops has been assessed by Waller (1992). Isolates vary both in their morphological characters in culture and their pathogenicity and host range. On PDA, colonies are whitish to dark grey with thick to sparse lawns of aerial mycelium. Conidia are hyaline, one celled, and cylindrical with obtuse ends. They form on light brown conidiophores in irregular acervuli, and upon maturity appear orange and slimy in mass. Acervuli develop in lesions on leaves, branches and fruit, and conidia in acervuli remain viable for long periods, even under adverse climatic conditions. The fungus is heterothallic and although the teleomorph can be readily induced in culture; it is observed rarely in the field. Appressoria are usually lobed (Plotez, 2009).

Disease Symptom

Anthracnose, the most important mango disease, is caused by the fungus *Colletotrichum gloeosporioides* (Alemu *et al*., 2014b). Flower blight, fruit rot and leaf spots are among the symptoms of this disease. Infection on the panicles starts as small black or dark-brown spots. These can enlarge, coalesce and kill the flowers, greatly reducing yield. On leaves, anthracnose infections start as small, angular, brown to black spots. Depending on the prevailing weather conditions blossom blight may vary in severity from slight to a heavy infection of the panicles. Young infected fruits develop black spots, shrivel and drop off. Fruits infected at mature stage carry the fungus into storage and cause considerable loss during storage, transit and marketing (Haggag, 2010).

Postharvest anthracnose appear as round brown to black lesion with an indefinite border on the fruit surface (Figure 1). Infection on large fruit does not normally develop into lesions. After initial establishment in the fruit, the fungus remains latent or dormant until the fruit begins to ripen. Dark depressed circular lesions then develop on the ripening fruit and increase rapidly in size. They may even cover the entire fruit surface in extreme sever cases. Lesions of different sizes can coalesce and cover extensive areas of the fruit, typically in a tear-stains pattern, developing from the basal toward the distal end of the fruit (Arauz, 2000). Lesions are restricted to the peel, but in severe cases the fungus can penetrate even the fruit pulp. In advanced stages of infection, the fungus produces acervuli and abundant orange to salmon pink masses of conidia appear on the lesions (Akem, 2006).

Figure 1. Advanced symptom of anthracnose disease on harvested mango fruit

Epidemiology and Disease Cycle

The injury caused by the anthracnose pathogen is dependent on temperature, humidity, rain, misty conditions or heavy dews at the time of blossoming. The optimum temperature for infection of anthracnose is around 25 ^{o}C

(Arauz, 2000). Continuous wet weather during flowering causes serious blossom blight. Relative humidity above 95% for 12 hours is essential for infection and development of *C. gloeosporioides* on mango fruit. However, conidia can survive for 1 to 2 weeks at humidities as low as 62% and then germinate if placed in 100% relative humidity. In general, infection is favored at temperatures ranging from 20 to 30°C. Within this range, there is considerable variation in the optimal temperature requirements for germination and appressorium formation among isolates of *C. gloeosporioides* from different locations (Arauz, 2000). Infection progresses faster in wounded tissues, and in ripe fruits (Prakash *et al.*, 1996).

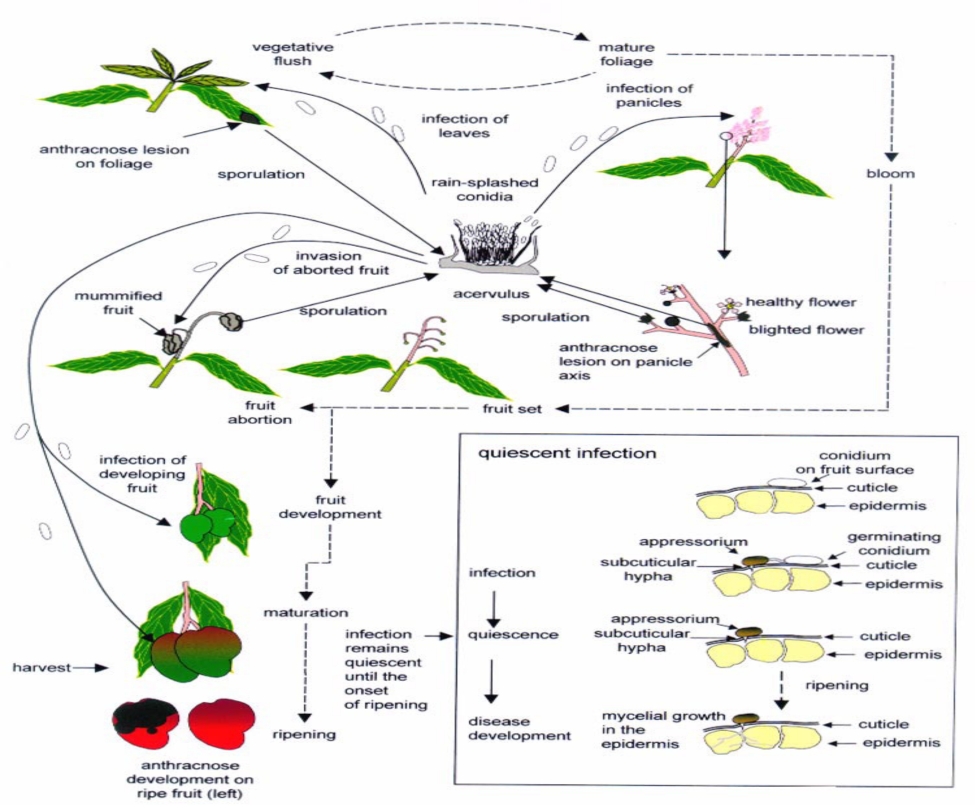

Figure 2. Disease Cycle of anthracnose (Arauze, 2000)

The pathogen survives on the infected and defoliated branch terminals and matures leaves, blighted peduncle, dead stem and diseased twigs attached to the trees (Figure 2). The pathogen develops on immature fruits and young tissues, spores germinate and penetrate through the cuticle and epidermis to ramify through the tissues. On mature fruits, infections penetrate the cuticle, but remain quiescent until ripening of the climacteric fruits begins (Nelson, 2008). It produces spores under favorable conditions and these serve as foci of infection for the succeeding bloom. Many cycles of disease can occur as the fungus continues to multiply during the season (Prakash, 2004). However, under tropical conditions, fresh supplies of spores are being continuously made throughout the year. Studies on the viability revealed that 70% spores of the fungus produced in acervuli on the twigs were viable. On diseased leaves, the fungus remained viable for 14 months (Prakash *et al.*, 1996).

Management of Mango Anthracnose

Control of postharvest anthracnose can be achieved from field management, after harvest treatments, or preferably, a combination of both. Management strategies must be efficient and cost effective, as well as safe to consumers, agriculture workers and the environment (Arauz, 2000; Akem, 2006). Any management strategy applied to manage anthracnose disease of mango should focus on both pre-harvest and postharvest management aspects.

Pre-harvest measures

Cultural control: The ubiquity of inoculums sources of *C. gloeosporioides* and its often rapid epidemic development under suitable conditions reduce the effectiveness of many general phytosanitary practices. Although general orchard hygiene has a place in integrated disease control, examples of good field control of *Colletotrichum* diseases affected solely by measures aimed at reducing inoculum sources are hard to find. Greater knowledge of the specificity of strains of the pathogen may enable effective phytosanitary practices to be developed (Ploetz, 2009).Since the development of the disease depends on wetness of high relative humidity, orchards should ideally be established in areas with a well defined dry season to allow for fruit development in condition unfavorable for disease development (Arauz, 2000). Altering the time of flowering to ensure fruit set and development occur during dry conditions, which focuses on off - season production for profitable market windows, helps in the control of anthracnose. According to Akem (2006), manipulating flowering such that fruit development during the least rainy time of the year is a possible disease avoidance strategy in tropical area. The incidence and severity of mango anthracnose can be very low in fruit developed completely in the dry season, even without the application of any control measure. Since Plant vigor plays an important role in keeping the plants free from twig infection, proper irrigation and fertilizer application are essential to maintain the tree vigor (Prakash, 2004).

Resistant varieties: Resistance has not been used as consistent means of control of mango anthracnose. This is partly because of the variable reactions in cultivars to the disease from one location to another. Although all commercial mango cultivars are susceptible to anthracnose, some are less susceptible than others (Akem, 2006). The cultivars Tommy Atkins and Keitt are less susceptible than others such as Irwin, Kent, or Edward. At present, none of the cultivars under production are significantly resistance to be produced without using some fungicides sprays protection in humid environment (Dodd *et al*., 1997). Because of market cosmetic standards, the level of anthracnose that develops under high disease pressure in less susceptible varieties such as Tommy Atkins is still unacceptable in a commercial situation, even in the less demanding local markets (Arauz, 2000).

Biological control: It is an approach using microorganisms to suppress plant diseases. Biological control attempts to increase crop production within existing resources and avoids development of pathogens resistant to chemicals. Relatively little research has been conducted on the biological control of anthracnose. Lise Korsten's group has the longest history in this area, and they have focused on using a gram positive bacterium *Bacillus licheniformis*, that resists desiccation and is food safe. In general, minor reductions in disease occur at 10 ^{o}C and 25 ^{o}C, either alone or in combination with fungicides (Govender and Korsten, 2006). Although less publicized, significant reductions have also occurred with Gram negative bacteria and other amendments (Vivekananthana *et al*., 2004).

Chemical control: Fungicide use is constrained by the limited number of products that are available, the pesticide regulations that exist in the producing and destination countries, and the products efficacy. In general, copper fungicides have the widest acceptance (Johnson and Hofman, 2009). However, copper fungicides are usually less effective under high disease pressure and phytotoxicity on mango (Ploetz, 2009). The fungicides Dithiocarbamet, mancozeb, febran provided excellent anthracnose control in the field (Akem, 2006). Fungicide with after infection activity for mango includes benzimidazoles, timidazole and prochloraz. Benomyl has been used in calander-base spray schedules, usually in a mix with protectant fungicides to delay the buildup of resistance in the pathogen population. It has also been applied as an eradicant spray following infection periods. Prochloraz has been used as a protectant or as an eradicant spray (Arauz, 2000).

Postharvest measures

Traditionally, postharvest control of mango anthracnose has aimed at reducing the level of quiescent infections on the fruit (Arauz, 2000). Even though fruit-to-fruit spread of anthracnose after harvest is unlikely, postharvest control of latent infection is often needed and used, especially if fruit are to be stored or shipped to other places (Dodd *et al*., 1997).

Physical method of control: The hot water treatment is being used successfully in many of the major mango producing countries of the world. It is simple and effective treatment that exists to reduce anthracnose decay in mature green harvested mangoes. It is effective in eradicating quiescent infections of the fungi that have become established on and beneath the cuticle and within the pedicel. Treatment effectiveness varies with infection level and storage temperature. It was reported that postharvest dips of fruit in hot water are considered as moderately effective against mango anthracnose, particularly under high disease pressure, unless they are applied in combination with fungicides (Kefialew and Ayalew, 2008). Basically, it consists of dipping the fruit in a hot water bath, with or without fungicide, at temperatures between 50 °C to 55 °C for 2 to 5 minutes. The treatment should be done soon after harvest, but no later than 2 days following harvest. The temperature of the water bath must be carefully controlled to within 0.5 °C to prevent fruit damage (Anonymous, 2002).

Biological control: Postharvest biological control of mango anthracnose has been attempted by some investigators. In an investigation with a strain of *Bacillus* sp. that exhibited in vitro activity against *C. gloeosporioides*, it was found that disease control in vivo was obtained when fruit were inoculated with the bacterium 24 hours prior to inoculation with the fungus, but not when fruit were inoculated with the pathogen first, which indicated that the quiescent phase of the fungus was not affected by the antagonist. It was indicated that the bioagent *Bacillus subtilis* significantly reduced anthracnose incidence in ripening fruits to much lower levels than those obtained by using a conventional single post-harvest treatment through prevention of early fruit infection (Senghor *et al*., 2007). Similarly, Kefialew and Ayalew (2008) reported that different isolates of bacteria and yeast antagonists significantly reduced anthracnose severity on fruit that had been artificially inoculated with *C. gloeosporioides.*

Use of plant extracts: Plant extracts and essential oils from different plant genera are gaining interest because of their apparently safe nature, wide acceptance by consumers and potential multi-purpose uses. The fungitoxic effects of crude extracts of different plant species indicate the importance of many plant species as a possible natural source of fungicidal materials. They contain complex mixtures of secondary metabolites, which are biologically active, endowed with antimicrobial, allelopatic, antioxidant and bioregulatory properties (Gottlieb et al., 2002). Different studies showed that extracts from different plant species showed potential on reduction of anthracnose development on mango fruit, indicating that biologically active plant derived product could play significant role in crop protection strategies (Alemu *et al*., 2014a).

Chemical control: The benzimidazoles are effective as postharvest treatments. Thiabendazole is almost as effective as benomyl (benomyl's formulation enables superior host penetration, a greater spectrum of activity and great efficacy), prochloraz and imazilil have been used as postharvest treatments. Although a non-specified strobilurin was tested in combination with a biological control agent for postharvest anthracnose control in South Africa, it was not tested alone (Govender and Korsten, 2006)

Stem end rot

Occurrence and Economic Importance

Stem-end rot is one of the most severe postharvest diseases of mango worldwide, cause's significant postharvest losses of fruit (Ni *et al*., 2012). Losses can increase during prolonged storage of fruit. The disease becomes more severe in an orchard as trees become older (Cooke *et al*., 2009).

Biology and Host Range

Stem-end rot diseases can be caused by the fungal pathogens *Lasiodiplodia theobromae, homopsis mangifera or Dithiorella dominicana* and *Colletotrichum gloeosporioides. Colletotrichum gloeosporioides* (the causal agent of anthracnose) can also cause symptoms at the stem-end of (Cooke *et al*., 2009). Botryosphaeriaceae species are known to occur worldwide, causing dieback, cankers, shoot blights, leaf spot, gummosis and fruit rots in a wide range of plant hosts which play important roles in agriculture and forestry (Ni *et al*., 2012). It can occur endophytically in healthy plant tissue and in plant debris and soil. They can colonize plant tissue through stomata, lenticels and directly on stems. In many hosts, invasion through lenticles 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 has also 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 slow lateral movement. Death of the portion above stem canker may result from tyloses and mycelium clogging the xylem vessels (Ramos *et al*., 1991)

Colonies on oat agar are greyish or mouse grey to black, fluffy with abundant aerial mycelium, reverse fuscous black to black. Conidiomata are immersed and thick-walled, and aggregated in clusters immersed in a stroma frequently up to 5 mm wide, erumpent, often with a distillate papillate ostiole. Conidiophore hyaline, simple, sometimes septate, rarely branched, cylindrical, arising from the inner layers of cells lining the conidiomatal cavity. Conidiogenous cells hyaline, simple, cylindrical to subobpyriform, holoblastic, annelidic. Conidia initially aseptate, hyaline, granulose, subovoid to ellipsoid-oblong, thick-walled, base truncate mature conidia one-septate, cinnamon to fawn, often longitudinally striate, 18-30 x 10-15 μm. Paraphyses when present hyaline, cylindrical, sometimes septate, up to 50 μm long. Conidiomata on leaves, stems and fruits immersed, later becoming erumpent, simple or grouped, 2-4 mm wide, ostiolate, frequently pilose with conidia extruding in a black mass (Punithalingam, 1976).

B. theobromae is a plurivorous, wound and secondary pathogen, and a saprophyte which is particularly common at relatively high temperatures. It has been found to affect a wide range of hosts including cocoa, citrus, groundnut, cotton, banana, Strophanthus intermedius grapevine, tea, sugarcane, tobacco, melon, cassava, sweet potato, yam and avocado. It is known to cause decay of the foliar crown of date palm, fruit rot of coconut, decline of Russian olive and a stalk end rot of Passiflora quadrangularis. It is also reported to cause leaf blight disease of Pandanus odoratissimus in Madras, India. It causes post-harvest rot of a range of vegetables. In Nigeria, it causes rot and blue stains of felled timber and soft rot of yam tubers (CABI, 2005).

Disease Symptoms
Blossom blight occurs as a result of the colonization of the blossom by the pathogen. The pathogen colonizes the tissue in favourable conditions causing twig die-back and extensive cankers of stems and trunks. The fungus stays dormant on the fruit until fruit begins to ripe (Govender, 2004). At the peduncle and pedicel tissues, rot takes place and in severe cases covers the entire body of the fruit. Symptoms appear as the fruit ripens and can vary according to the causal agent. Generally, a brown, soft decay starts at the stem end and rapidly rots the whole fruit. Infected fruit may split open as they collapse. A straw-colored fluid drains from the stem-end or from splits in the side of the fruit. Steel-grey mycelium may cover the surface of fruit (Parakash, 2004). The fungus can spread to adjacent healthy fruit in physical contact. Lesions may also occur away from the stem-end, particularly if the fruit has been injured. Flesh of infected fruit has an off flavor. Lesions caused by *P. mangiferae* are generally firmer, have a defined margin, and spread more slowly than those caused by other stem-end rot fungi. Stem-end rot caused by *P. mangiferae* can be distinguished from anthracnose at the stem end by differences in the fruiting bodies *P. mangiferae* produces dark, pinhead-size fruiting bodies; *C. gloeosporioides* produces pink spore masses (Parakash, 2004; Cooke *et al*., 2009).

Figure 3. Disease symptoms of stem-end rot on harvested mango fruits

Epidemiology and Disease Cycle
The fungi live within branches without causing symptoms (endophytic growth) and colonise inflorescence tissue by endophytic growth of hyphae, reaching the stem end of fruit several weeks after flowering (Govender, 2004; Cooke *et al*., 2009). The fungi do not spread into fruit until after harvest. Some of the fungi causing stem-end rot may also be harboured in tree litter and in the soil. Fruit can also be infected by soil contact at harvest (Cooke *et al*., 2009). The exact mode of entry of Botryospareia on mango tree is not known but natural openings wounds caused by pruning, insects and sunburn is considered the most likely route of infection (Figure 4). Fruit invasion by the pathogen is through the stem ends causing latent infection. After latency is broken systemic spread of the pathogen can occur. High humidity and movement of water is generally responsible for the release and dispersal of Botryospareia conidia from limbs of various woody hosts. Creswell and milholland (1988) found that conidia are present in rain water all year, indicating the importance of rain as a mechanism of pathogen spread. Fruiting structure of Botryospareia spp. are often produced on old mango tree litter, enabling easy spore dispersal by means of rain splash and wind. Botryodpareia overwinter as a black pycnidia and perithecia in wart like stomata on living and dead cankered limbs of trees of mummified fruit (Govender and Korsten, 2006).

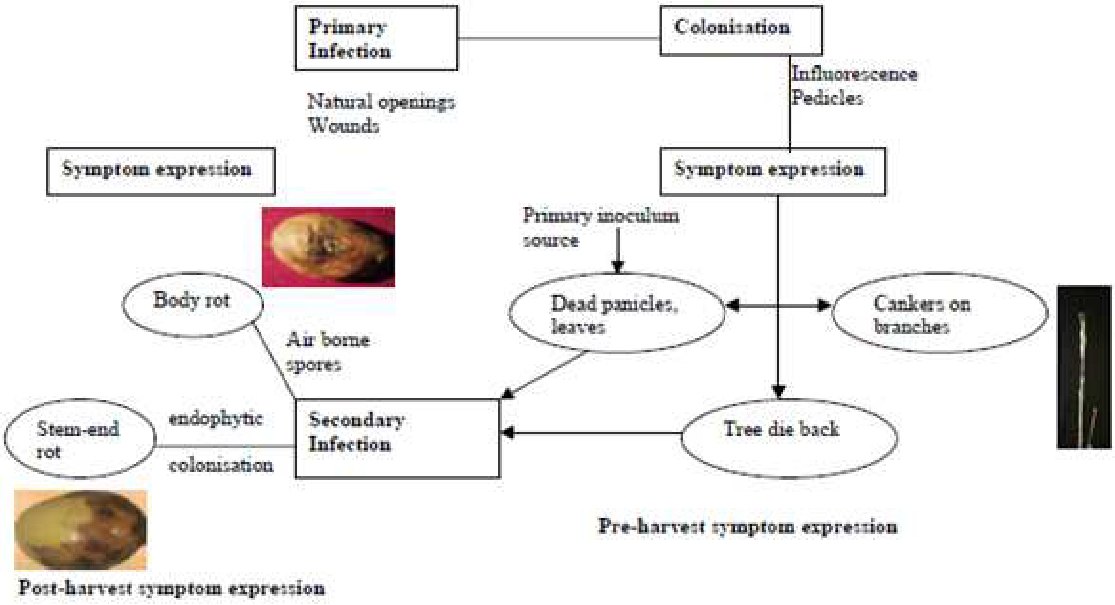

Figure 4. Disease cycle of stem end rot of mango (Govender, 2004)

Management of Stem-end rot of mango

Infection of mango tree and fruit by Botryospareia spp. can result in many different disease symptoms. The development of control for economically important pre- and postharvest disease caused by these fungi should include a focus on pathogen epidemiology. The fungi exist endophytically in the mango tree, spread systematically through the vascular system and express symptom pre-and postharvest if pathogen invasion and colonization is not inhibited chemically or biologically.

Pre-harvest control: Disease incidence variation seems to relate to the fluctuation and extent of latent infection of Botryospareia in fruit and tree. Latent infection can be influenced by orchard fungicide spraying, orchard sanitation, cultivar resistance, climatic and tree age. Some preharvest control measured aimed at reducing such infection, therefore, includes planting disease resistant or tolerant cultivars, reduction of potential wounds and limiting the chance of preharvest fungal inoculum deposition. Preharvest fungicidal sprays or the application of biological agents such as bacillus licheniformis and covering fruit with polyethylene caps was found to reduce the incidence of fruit rots (CABI, 2005).

Postharvest control: In recent years, the emphasis has been on the development and improvement of postharvest practices such as irradiation, warm water treatment and controlled atmosphere and low temperature storage (Govender, 2004**;** Cooke *et al*., 2009). The alternate use of increased CO_2 level has proven to be useful in controlling postharvest pathogens during long term, low-temperature storage. Dipping of fruits in hot water (55 ^oC) amended with fungicides such as prochloraz, can adequately control most of the superficial infection and prevent transmition of inoculum. Biological control measure is at an early stage of commercialization. A warm water dip *B.lichiforms*, followed by reduced concentrations of prochloraz was found to effectively control various mango diseases, including fruit rots (CABI, 2005; Cooke *et al*., 2009).

Conclusion

Postharvest diseases of mango can cause serious losses of fruits worldwide. The observable external symptoms often only become apparent after ripening, by which it is usually equated with the edibility of the fruit and causing serious losses during storage. The economic costs of such postharvest losses are higher than the field losses. The successful management of such diseases depends on understanding the biology of the pathosystem, the conditions that promote disease development, and the economics, efficacy and market acceptability of the various control measures. Nowadays, integrated disease management is the preferred strategy because of increased understanding on residual effects of chemical control on non target organisms and environment as well as the limitation of a single alternative management option to achieve the same level of control and reliability as that of chemicals. Thus, integration of a number of practices with the aim to reduce or eliminate negative side effects caused by chemicals used for controlling major postharvest diseases of mango is the most realistic option for solving the problem.

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